Ground motion effects in future colliders

NPSS technology school

Snowmass 2001
July 17

Andrei Seryi, SLAC

NPSS Technology school, July 17, PM
NPSS noon lecture, July 18

NLC

Tuesday July 17, PM

Ground motion, Optimal Tunneling and Environmental Considerations for Future Colliders

Ground motion in future colliders — Andrei Seryi (SLAC)

Optimal tunneling for future colliders — Wilhelm Bialowons (DESY), Chris Laughton (Fermilab)

Conventional alignment - Now and in the future — Catherine LeCocq (SLAC)

Beam based alignment - From an art to indispensable everyday tool — Peter Tenenbaum (SLAC)

Wednesday July 18, noon

Ground motion effects in future accelerators
- what accelerator and non-accelerator physicists should know about it

Andrei Seryi (SLAC)

NLC

Content

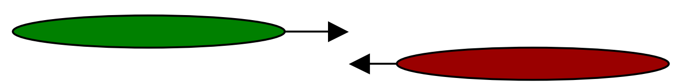
- **Why we care about ground motion?**
- **Basics of ground motion**
- **Ground motion effects in**
  - **Hadron colliders (VLHC)**
  - **Linear colliders (NLC, JLC, TESLA, CLIC, …)**
- **Ground motion studies**
  - **Correlation**
  - **Slow motion, its effects**
  - **Site resonances**
- **Stabilization of beam and luminosity quality** ***(briefly)***

Why do we care about Ground Motion

- **Linear Collider**
  - **Collide small beams (nanometers); very small beam emittance**
- **Very Large Hadron Collider**
  - **small emittance; long ring (~230 km); long store (hours) time;**
  - **colliding beam size is still big (~250nm)**

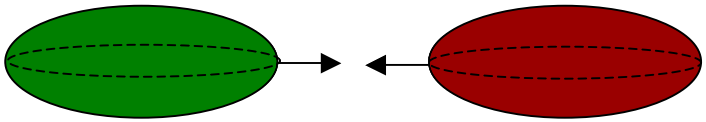
- **Ground Motion** and vibrations continuously **misalign** components of a collider and can result in

  - **offset at IP**



LC

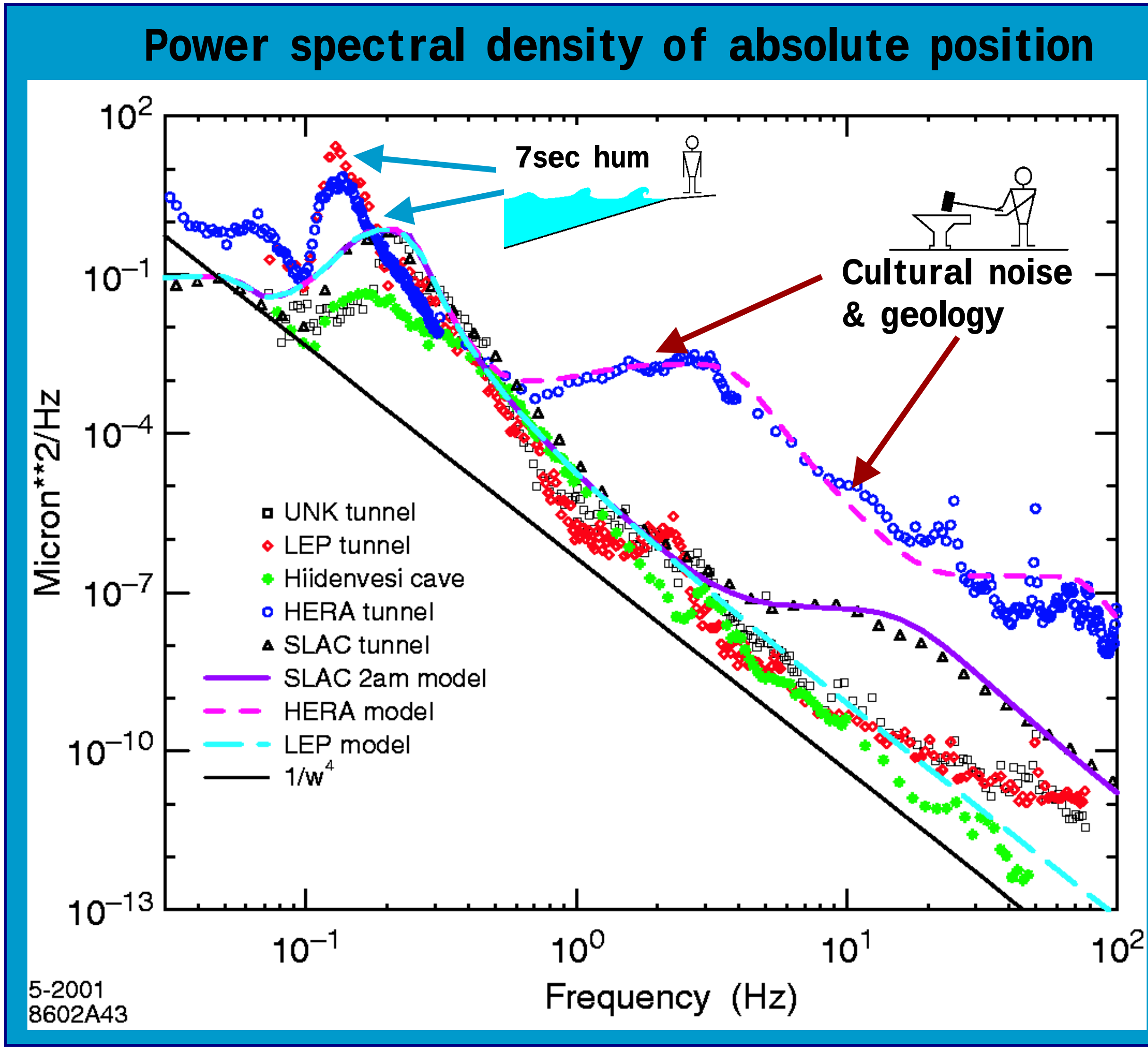
  - **emittance growth**



LC and VLHC

Ground Motion basics
example of measured spectra

- **Fundamental – $1/\omega^4$**
- **Quiet & noisy sites/conditions**
- **Cultural noise & geology very important**
- **This is spectrum of absolute motion of <u>one</u> point**



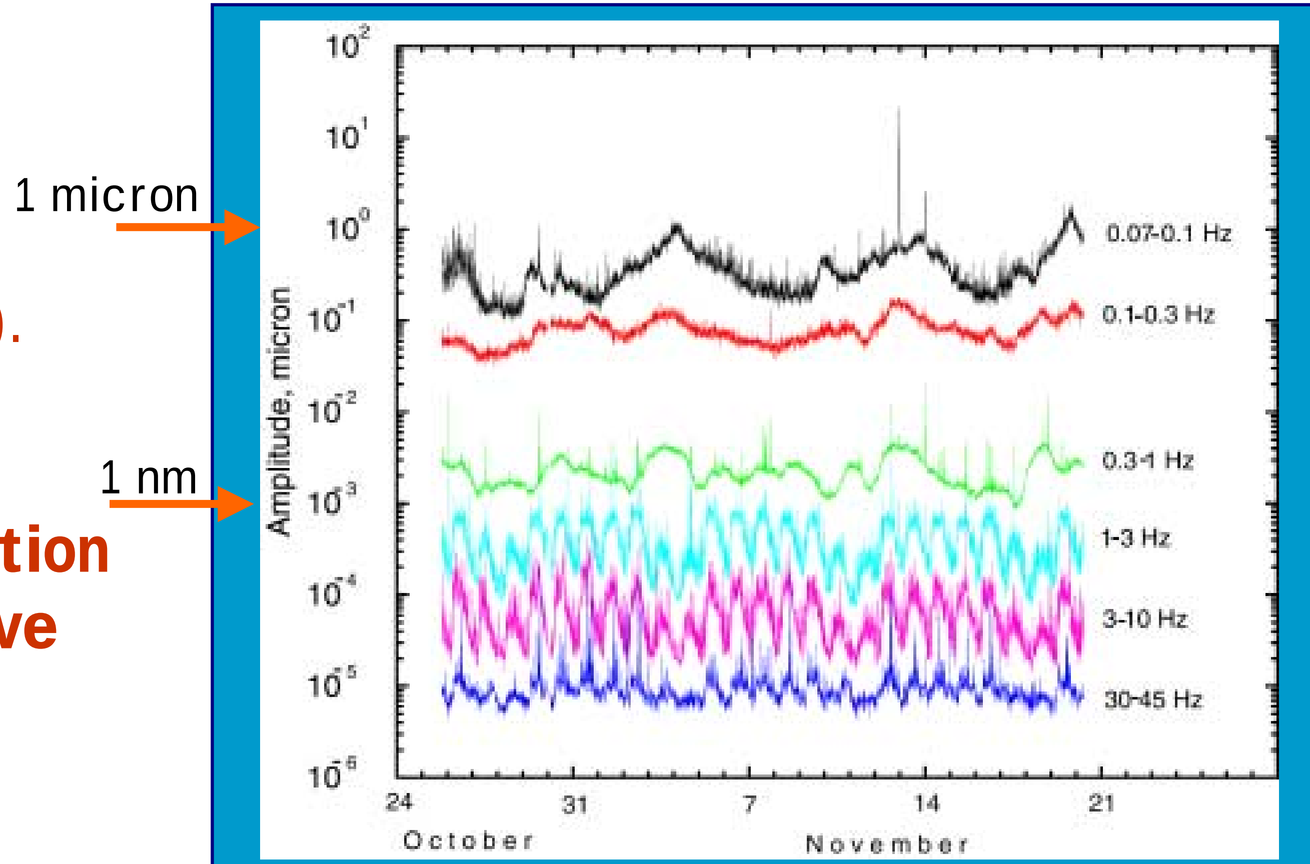
Natural ground motion is small

Example

This is **absolute** motion (one point with respect to "stars").

One needs **correlation** data to find **relative** motion

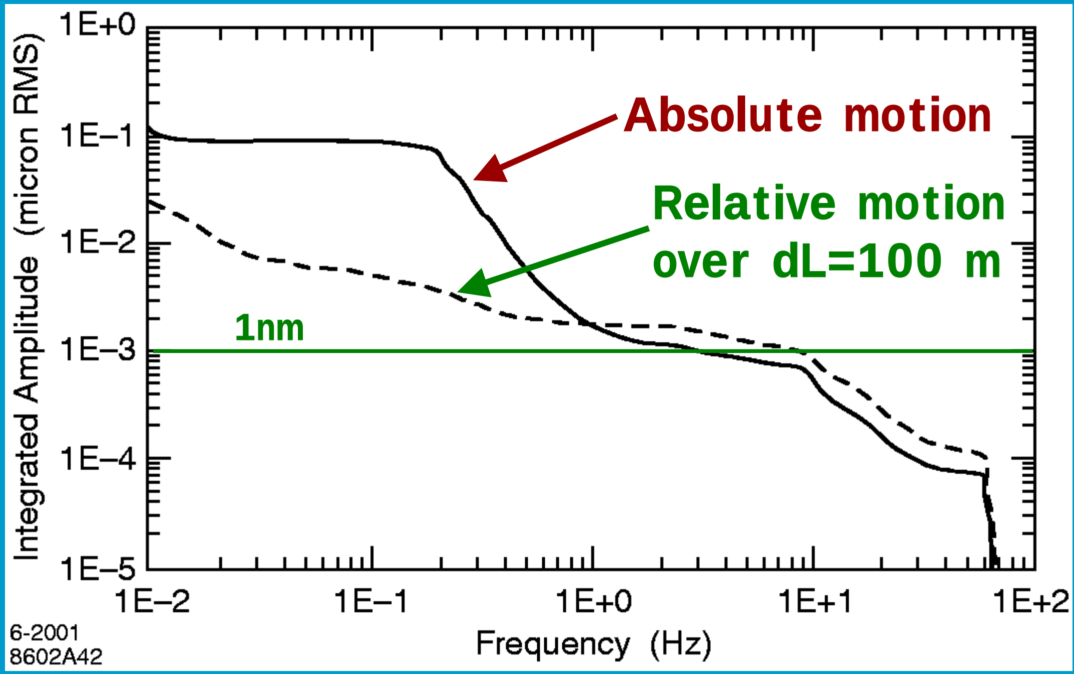
and to build a **2D** spectrum of ground motion **P(ω,k)**



Rms displacement in different frequency bands. Hiidenvesy cave. [V.Juravlev et al. 1994]

Correlation: relative motion of two elements with respect to their absolute motion

- **Care about relative, not absolute motion**
- **Beneficial to have good correlation (longer wavelength)**
- **Relative motion can be much smaller than absolute**



Integrated (for $F>F_o$) spectra. SLC tunnel @ SLAC

Correlation in time and space

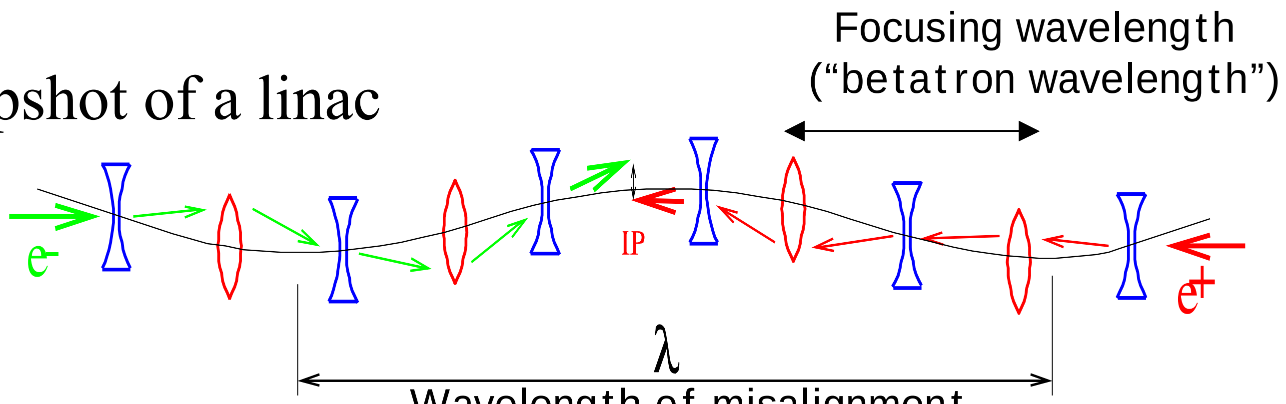
Correlation: relative motion of two elements with respect to their absolute motion

Correlation is a function of separation in **time** and in **space** :

time is important : since a collider has certain repetition rate

space is important : since a collider has certain focusing wavelength

Snapshot of a linac



Ground motion effects on VLHC *emittance growth*

- Beam size is large ~250nm >> ground motion => no effect on IP beam offset

- Ground motion produces emittance growth:
  - betatron oscillations => decoherence => emittance growth
  - lowest contributing frequency **$f=\Delta\nu * f_0$ ~250Hz**
    (f_0 – rev.freq. ~1.3kHz; $\Delta\nu$ – fractional tune ~0.18)

Growth rate $d\varepsilon_n/dt \approx f_0 \gamma \langle\beta\rangle N (\sigma/F)^2/2$ [V.Lebedev et al.,1994]

Initial emittance ε_n=1.5μm double in 2.5 hours with 0.3nm of quad vibration*

*parameters are for the high field VLHC with 87.5 TeV beam; without feedback

Ground motion effects on VLHC *emittance growth*

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- 0.3nm of quad vibration at F> **250Hz is not crucial – natural ground motion much smaller**
- **Tolerance can be eased ~10 times with feedbacks**

- Feedbacks required not primarily because of ground motion
- But to suppress TMCI and resistive wall instability with ~1 turns growth rate <- more immediate concern

- In deep tunnel, ground motion ~ OK for VLHC
- Still, be very careful with equipment generated vibrations (cryo-equipment, etc.), and
- also with ground-quad difference (girder , cryostat)

Two effects of ground motion in Linear Colliders

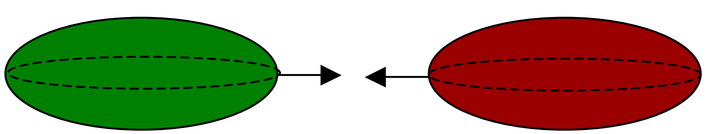
frequency

'slow motion' | **'fast motion'**

$F_c \sim F_{rep}/20$

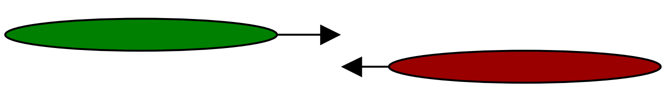
Beam offset due to **slow motion** can be compensated by feedback

beam emittance *growth*

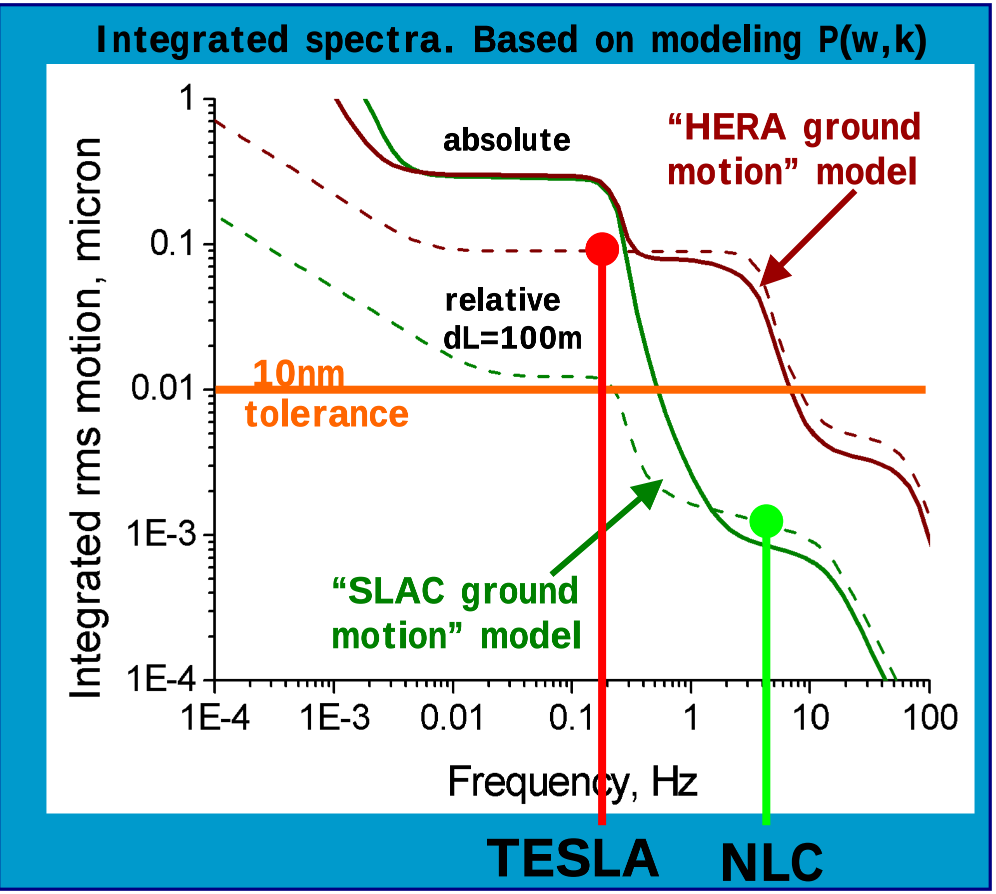


Beam offset **c**annot be corrected by a pulse-to-pulse feedback operating at the F_{rep}

beam offsets at the IP



Fast Ground Motion in NLC and TESLA



For linac quadrupoles, tolerance roughly 10nm for both
(-> $0.25\sigma_y$ NLC ; $0.1\sigma_y$ TESLA)

Rep.Rate of bunch trains:
120Hz @ NLC -> F_C ~ 6 Hz
5Hz @ TESLA -> F_C ~ 0.2 Hz

NLC is OK at quiet site

For TESLA, motion above tolerance even at ~quiet site

But hopefully TESLA can rely on fast correction within bunch train (rep.rate of bunches 3 MHz F_C -> 100kHz)

Rough scale of tolerable uncorrelated ground motion

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- VLHC: 0.3nm of quad vibration above 250Hz; ~3nm with feedback (high field VLHC with 87.5 TeV beam)
  - Initial emittance ε_n=1.5μm double in 2.5 hours
    - Achievable. Care about in-tunnel noise; cryostat vibrations

- TESLA: ~10nm above 0.2 Hz; much more relaxed with fast intratrain correction
  - Produce **0.1**σ_y offset at IP
    - Fast intratrain correction is required

- NLC: ~10nm above 6 Hz;
  - Produce **0.25**σ_y offset at IP
    - Achievable. Care about in-tunnel noises

Differences of approach to collision stability

- **TESLA**
  - Cannot rely on quiet site
  - Rely on fast correction within bunch train

Both require good girders
(low amplification by cryostat)

- **NLC**
  - Rely on quiet site
  - Actively stabilize final doublets
  - In addition, use fast correction within bunch train
    (more difficult because of 1.4ns bunch separation)

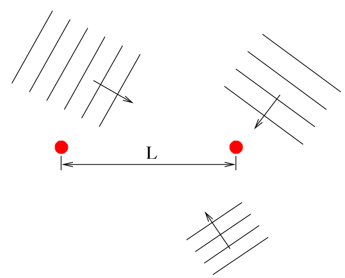
Ground motion studies
several examples

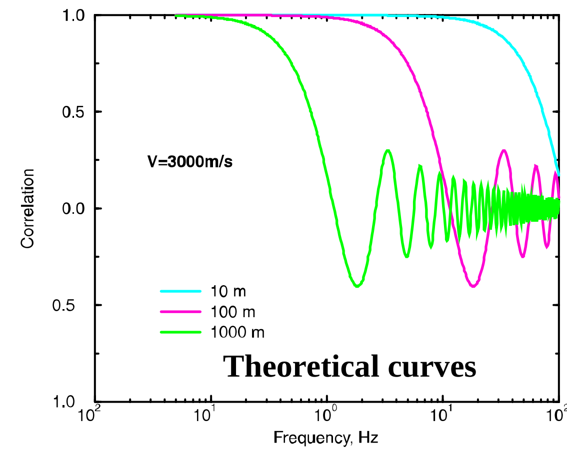
- Fast motion
  - Correlation studies
  - Effect of tunnel location
- Slow motion studies
  - Diffusive or ATL motion
  - Systematic motion
  - Effects of slow motion
  - Site resonances

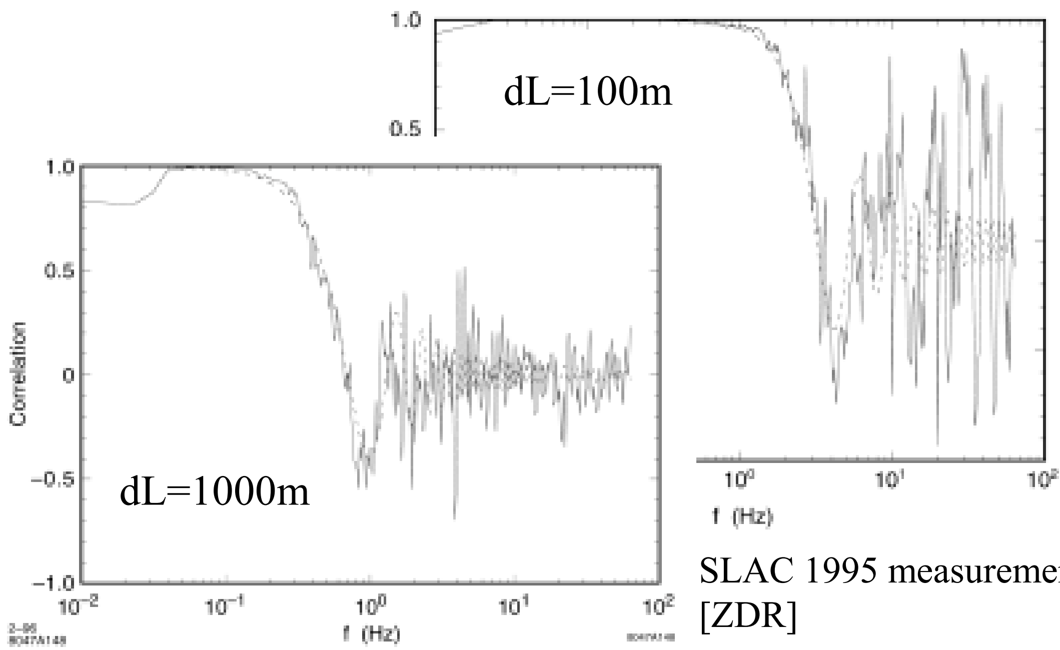
Correlation measurements and interpretation

In a model of plane wave propagating on surface

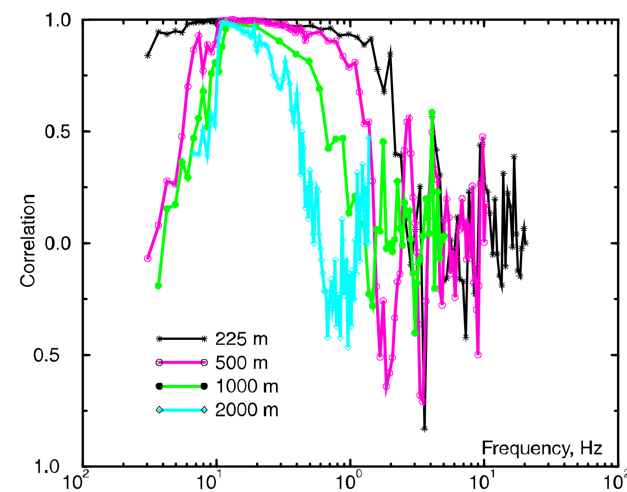
correlation = <cos(ωΔL/v cos(θ))>$_\theta$ =
=J$_0$(ωΔL/v) where **v-** phase velocity







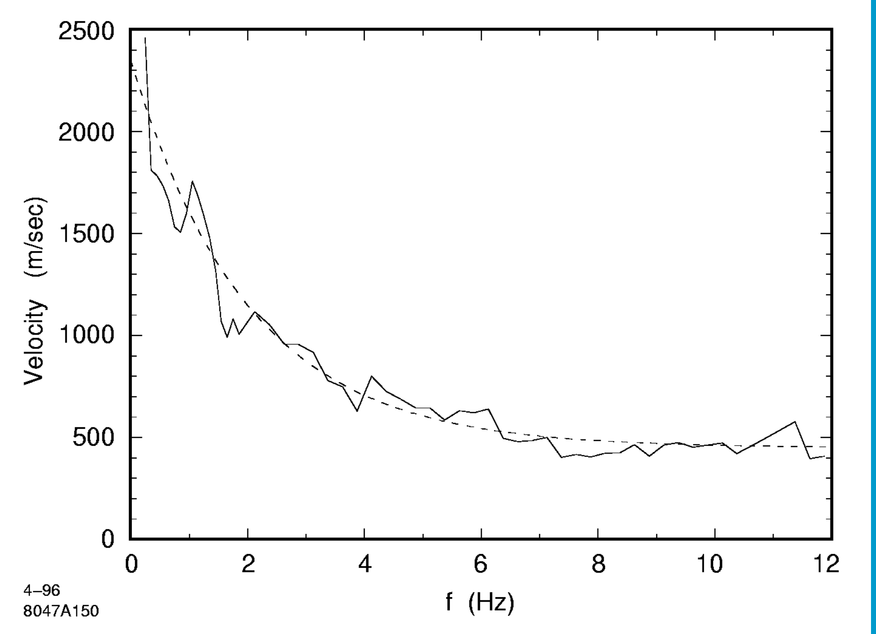
SLAC 1995 measurements [ZDR]



BINP@CERN LEP 1993 measurements [V.J. et al.]

Correlation measurements and interpretation

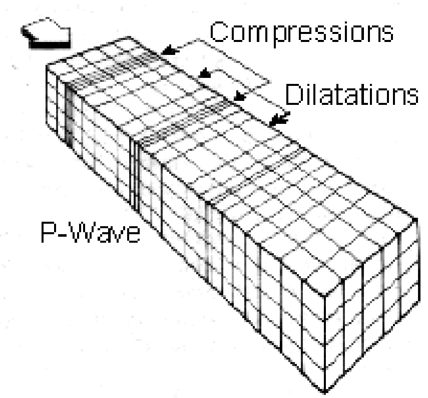
- **Phase velocity** found in correlation measurements characterize surrounding media.
- **Increase** of **v** at lower frequency corresponds to **increase of rigidity** with **depth.**
- **Shallow** tunnels like **HERA, SLAC**, **TT2A**, show **v~400-2000m/s**
- **Deep** tunnels like **LEP** show **v ~ a few km/s**
- **Wave character of motion F>0.1Hz**



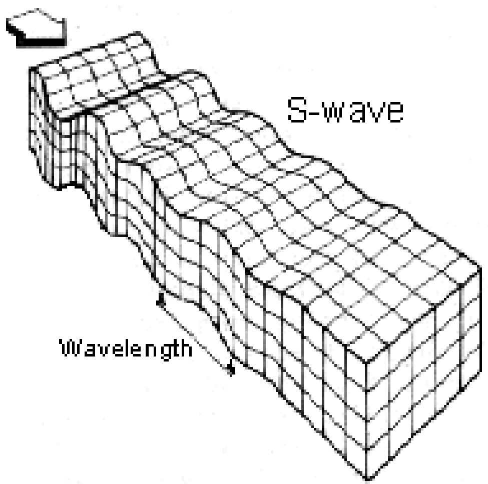
Phase velocity found in SLAC studies [ZDR]. Fit V(f)=450+1900exp(-f/2), m/s.

Waves in infinite homogeneous elastic media

P-wave, (primary wave, dilatational wave, compression wave)
Longitudinal wave. Can travel trough liquid part of earth.



Velocity of propagation $$v_P = \sqrt{\frac{\lambda + 2G}{\rho}}$$



S-wave, (secondary wave, distortional wave, shear wave)
Transverse wave. Can not travel trough liquid part of earth

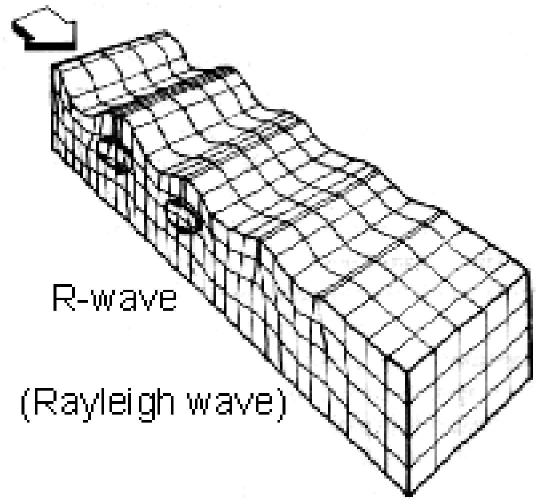
Velocity of propagation $$v_S = \sqrt{\frac{G}{\rho}}$$ typically $$v_S \approx \frac{v_P}{2}$$

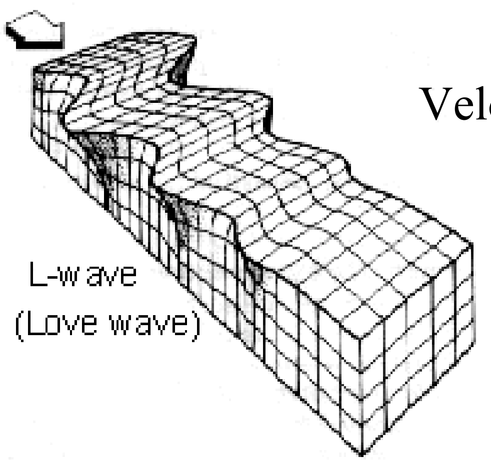
Here ρ- density, G and λ - Lame constants: $$G = \frac{E}{2(1+\nu)} \qquad \lambda = \frac{\nu E}{(1+\nu)(1-2\nu)}$$

E-Young's modulus, ν - Poisson ratio

Waves in elastic half-space

In addition to p-waves and s-waves,
the half-space can also withstand the waves
that propagate and localized ***near the surface***





Velocity of propagation $v_R \approx v_S$

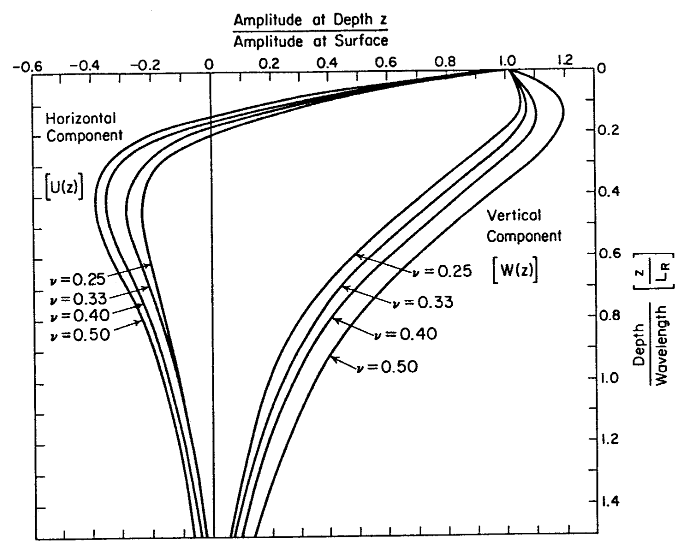


Figure 3-14. Amplitude ratio vs. dimensionless depth for Rayleigh wave.

Amplitude of Rayleigh wave decrease **exponentially** with depth

Ground motion vs geology, location, depth

- **Geology: hard rock is preferable**

  => fast motion is better correlated (as v larger and λ longer)

- **Location**:

  => avoid external <u>cultural noise</u>,
  especially for shallow tunnel

- **As geology and noise depend on depth, we have one more degree of freedom**

What is best way to hide from external cultural noises?

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Attenuation of waves:

$$\sqrt{\frac{r_0}{r}}\ \exp\left(-\frac{\pi(r-r_0)}{Q\lambda}\right)\ \exp\left(-\frac{h}{\lambda}\right)$$

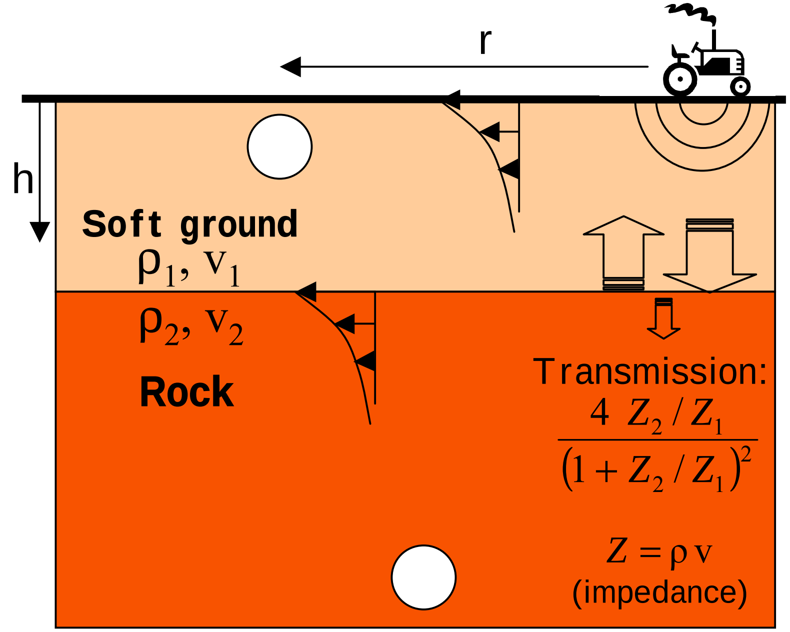
Rayleigh on-surface

geometric dissipative

$$\frac{r_0}{r}\ \exp\left(-\frac{\pi(r-r_0)}{Q\lambda}\right)$$

p- or s-waves in depth

λ – wavelength; v – sound velocity; $r_0 \sim \lambda/2$; Q – can be 10 – 25 for near surface ground and up to hundreds for bedrock



- **Go deep if cannot go far from noise**
- **Going reasonably deep is more effective than going remote, because attenuation of on-surface waves is slower than in-depth waves**
- **Typical layered ground structure helps prevent noise penetration to lower layers**

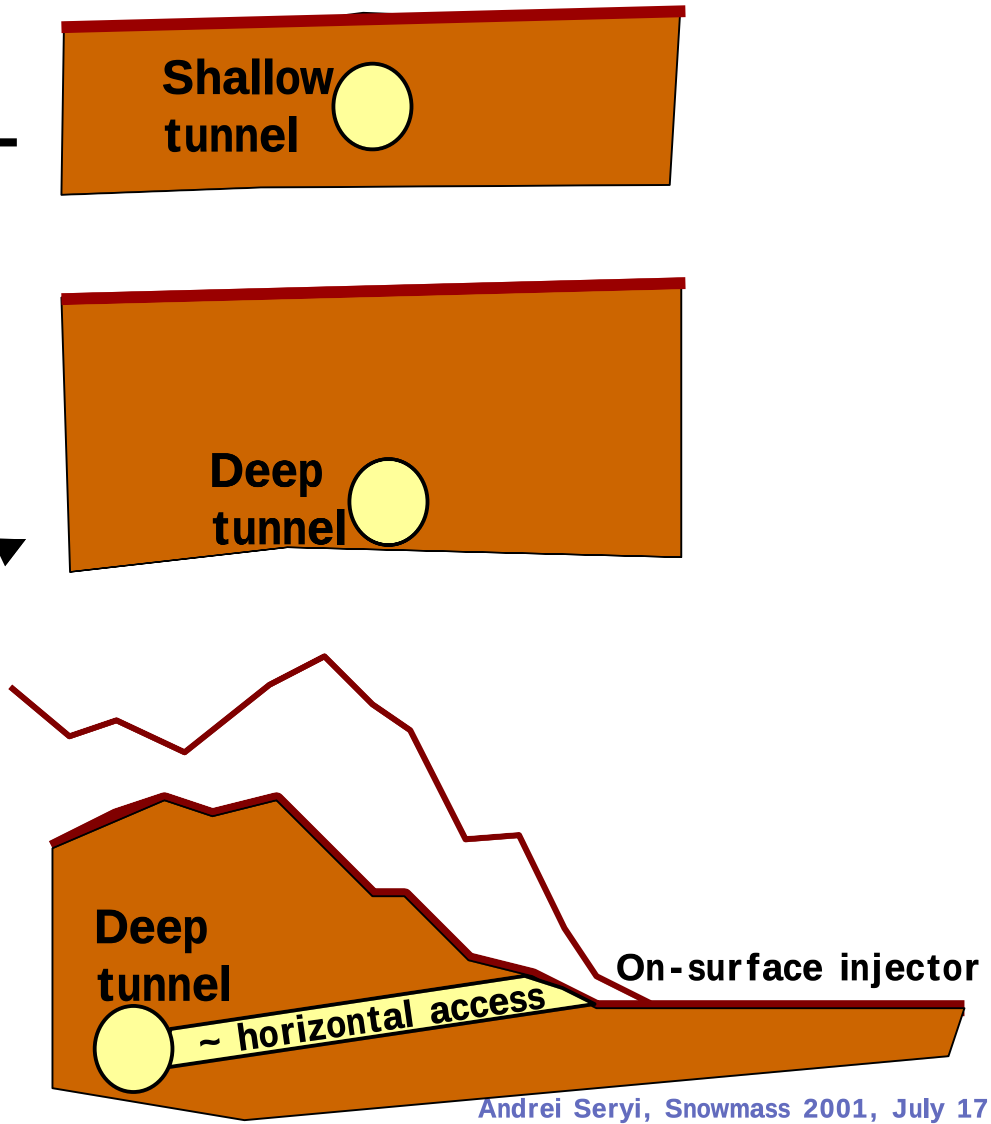
Ideally, the impedance of the top layer(s) should be << than of the lower layers

100m depth worth ~ km in r

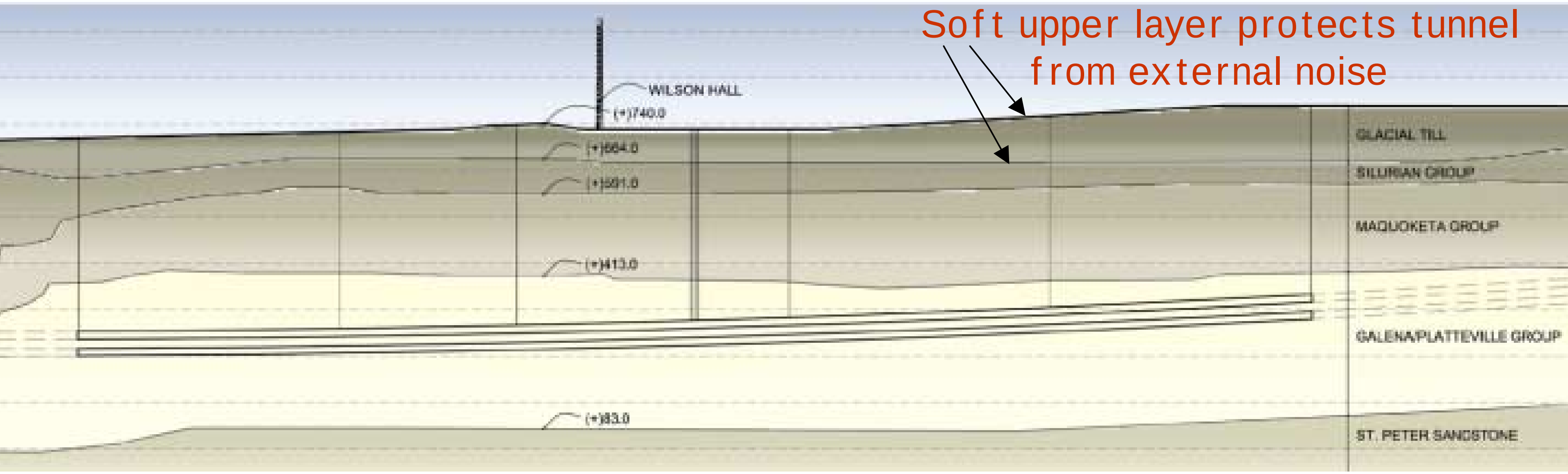
NLC sites & Ground motion

- **NLC sites considered in California and Illinois so far:**

Also considered for VLHC

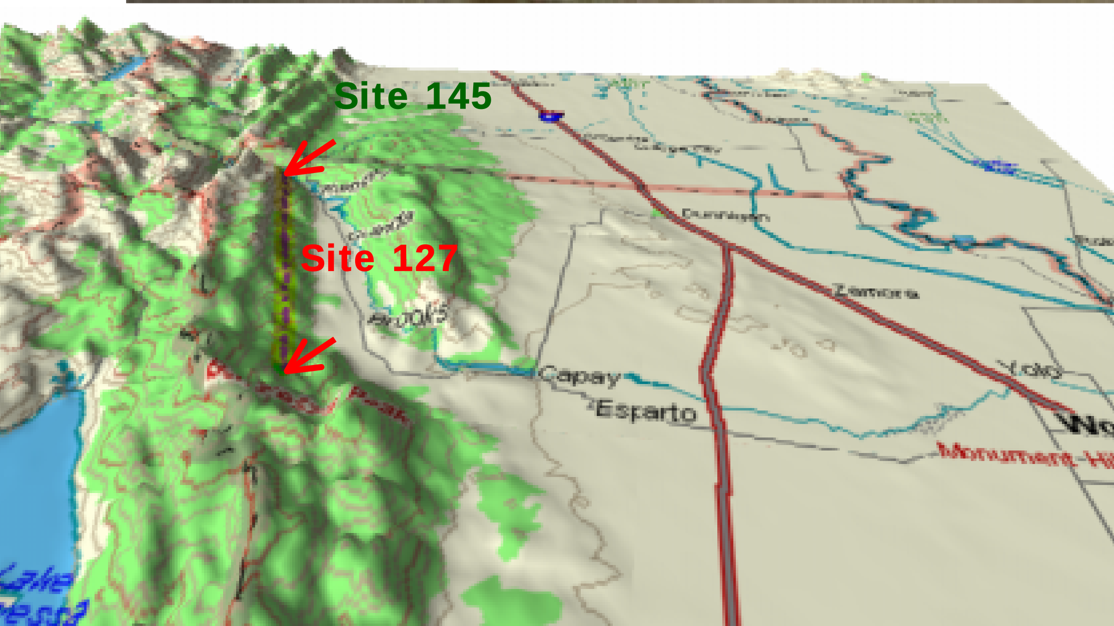


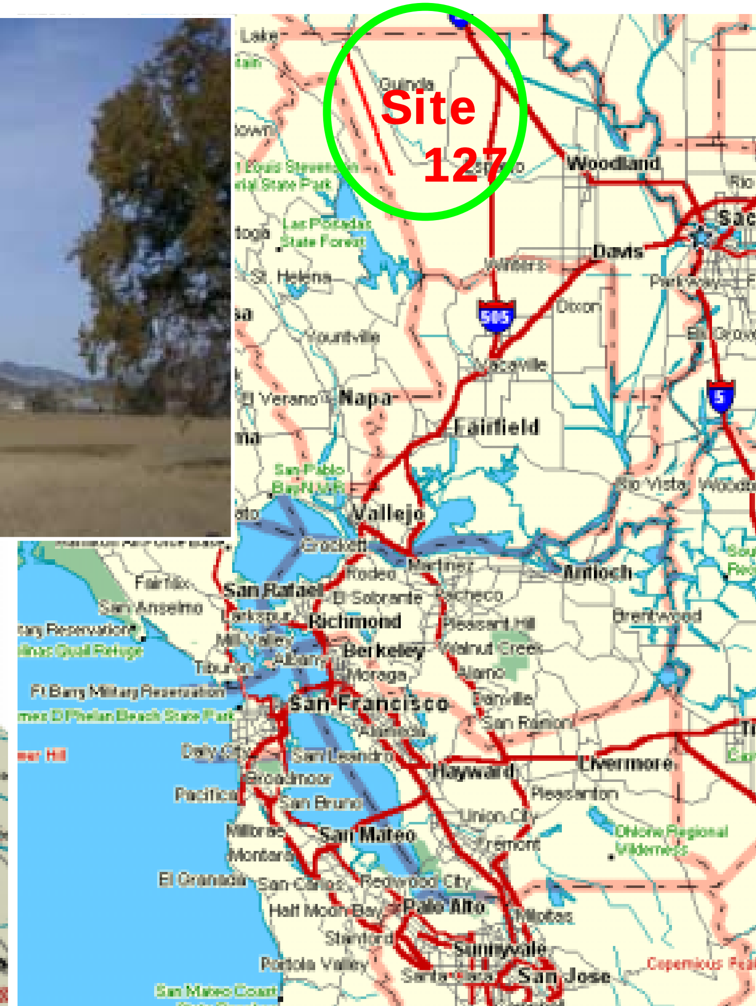
NLC deep tunnel @ Fermilab



- Tunnel is placed **~100m deep in geologically (almost) perfect Galena Platteville dolomite platform**
- **Top ground layer is soft** (NUMI geological studies : $v_2/v_1 \sim 5/1$ for 1st transition) – **this increase isolation from external noises**
- When choosing depth – **optimize** not only for boring conditions, but **also for vibration attenuation – each layer makes tunnel more quiet**

NLC deep tunnel CA sites 127&145





Fast Ground Motion again
geology & cultural noise

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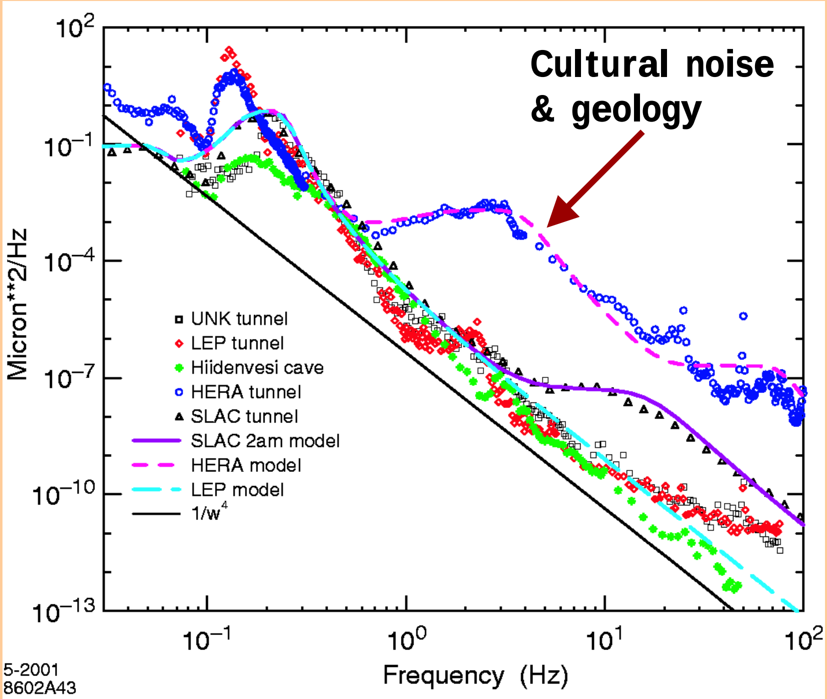
- **Deep tunnels are quiet**
  - **Care about in-tunnel noise**
- **Shallow (not deep) sites usually noisy**
  - **Because of cultural noise**
  - **Resonance of clay/sandy site itself**
- **E.g. resonance of LIGO sites:**
  - **1-5Hz Livingston LIGO site (water logged clay)**
  - **5-12Hz Hanford LIGO site (dry sand)**

(Courtesy LIGO & F.Asiri)



- **Resonance of a sandy HERA site + cultural noise may be reason for large noise at DESY**
- **Relative motion ~ 100nm, F>1Hz**

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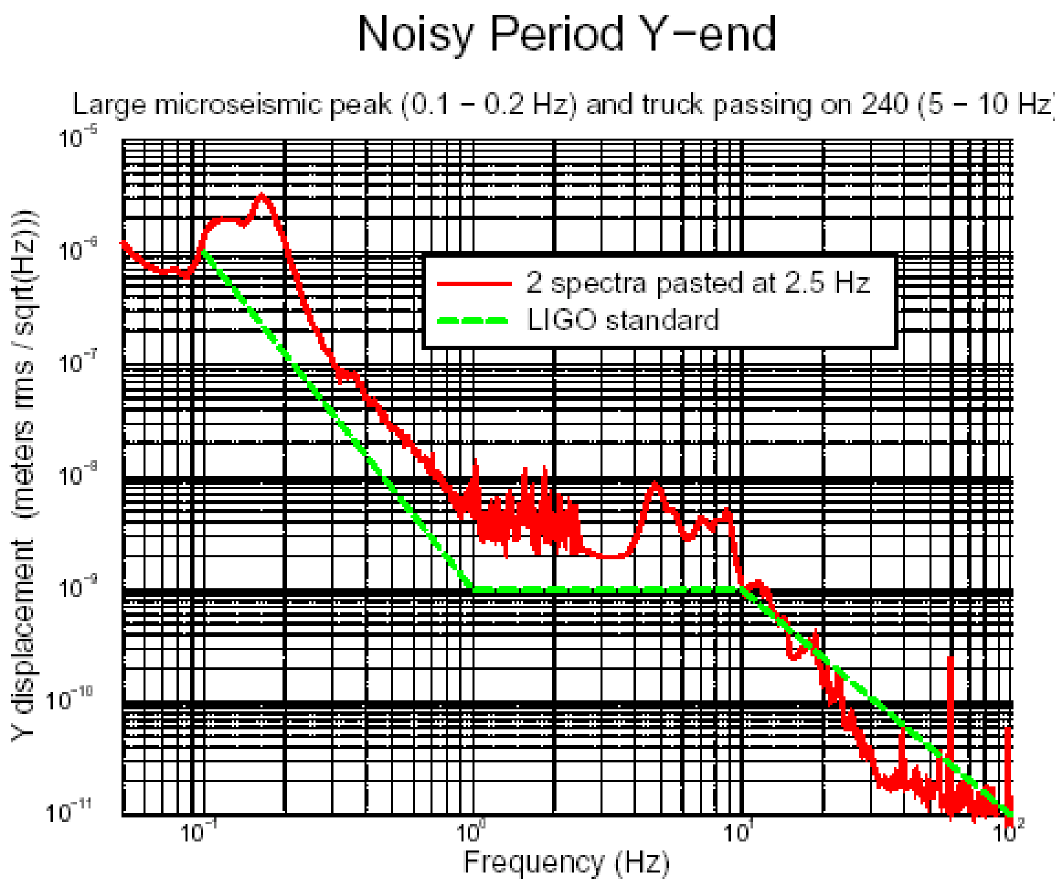
Resonance of shallow sites

- **Resonance of LIGO sites:**
  - **1-5Hz Livingston LIGO site (water logged clay)**
  - **5-12Hz Hanford LIGO site (dry sand)**



(Courtesy LIGO & F.Asiri)

Slow motion (minutes - years)

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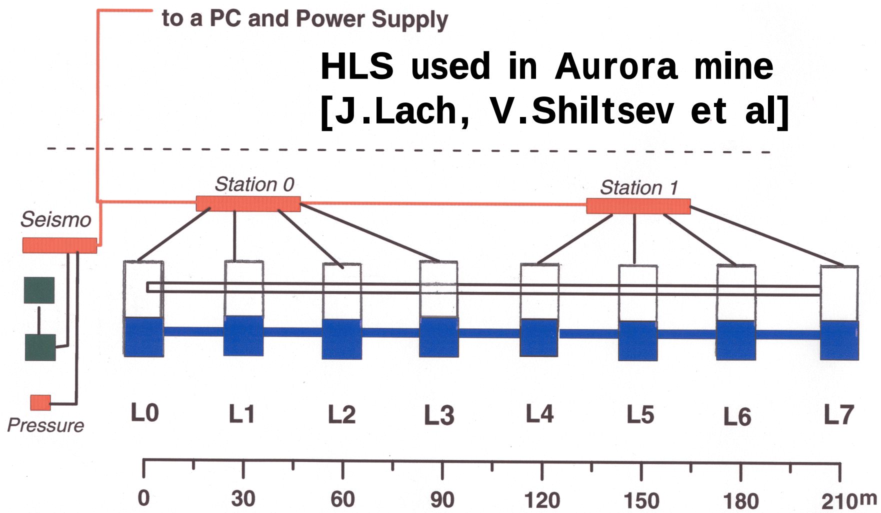
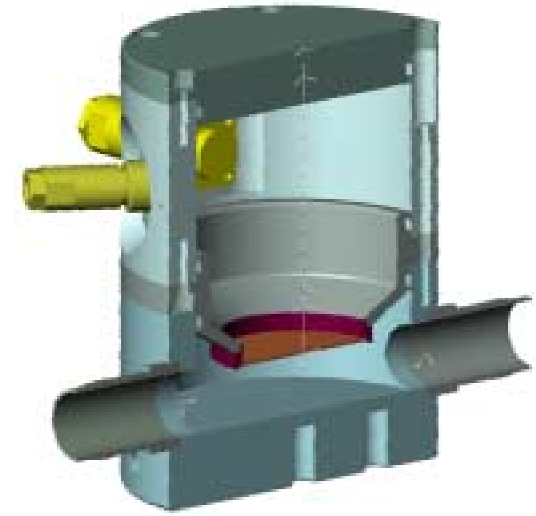
- **Diffusive** or **ATL** motion: $\Delta X^2 \sim ATL$
  (minutes-month)
- Observed 'A' varies by ~5 orders: 10^{-9} to 10^{-4} $\mu m^2/(m \cdot s)$
  - **parameter 'A' should strongly depend on geology -- reason for the large range**
  - **'A' reported to depend on tunnel construction method: blasting/TBM [Shigeru Takeda]**

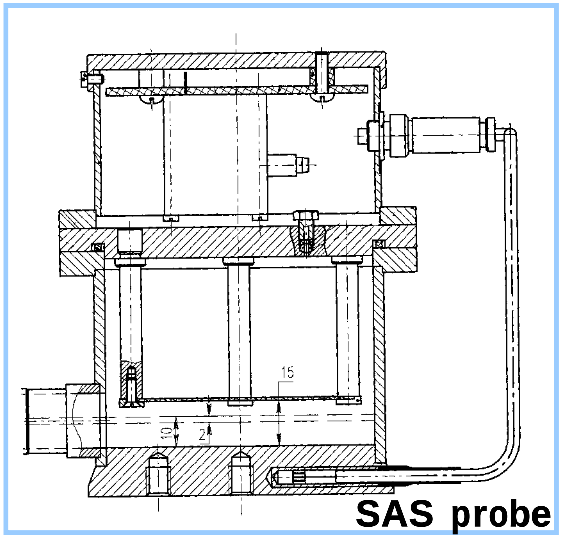
- **Systematic** motion [R.Pitthan] : ~linear in time
  (month-years)
- **In some cases can be described as ATTL** law :
  - SLAC 17 years motion suggests $\Delta X^2 = A_S T^2 L$ with
    $A_S \sim 4 \cdot 10^{-12}$ $\mu m^2/(m \cdot s^2)$ for early SLAC

How one would measure slow motion?
Example: Hydrostatic level system





Single tube version



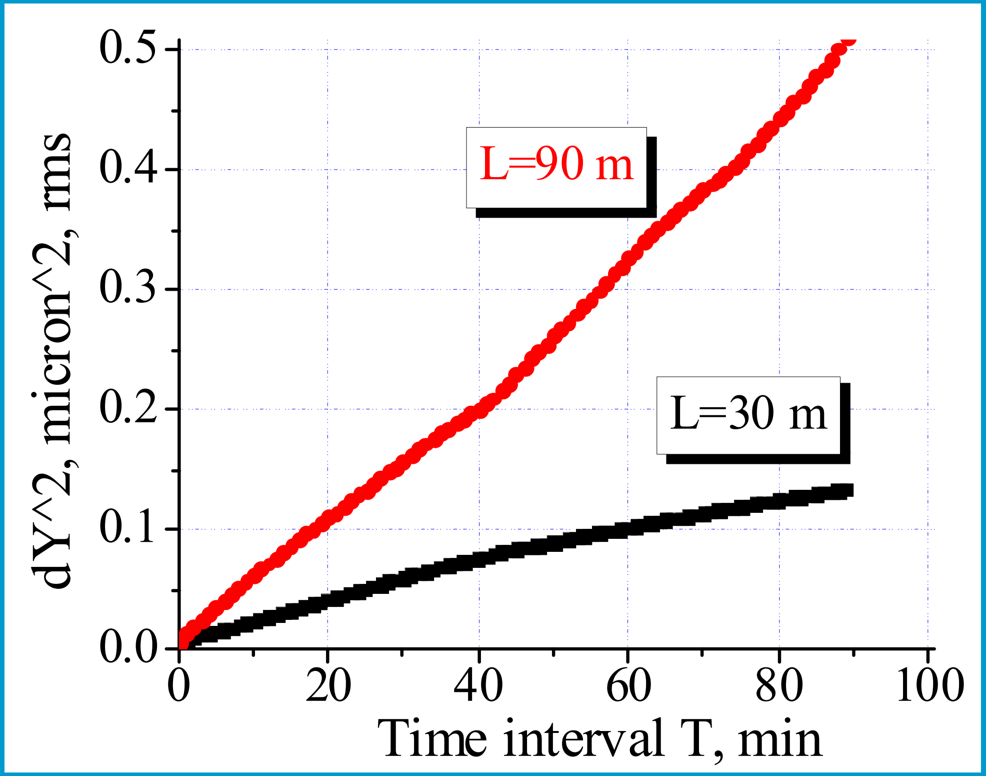
New HLS developed at Budker INP that will be used in further studies

Slow motion *example*

- Slow motion in Aurora mine exhibit ATL behavior

- **Here A~ $5*10^{-7}$ $\mu m^2/m/s$**

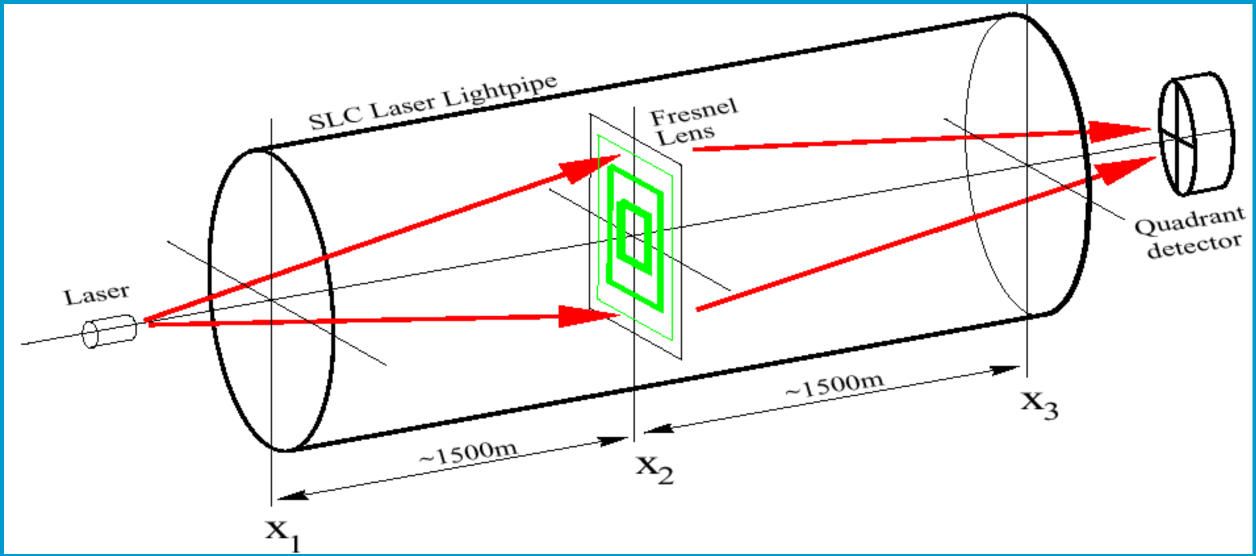
- Further measurements with improved HLS system are planned to improve signal/noise



Slow motion in Aurora mine [J.Lach, V.Shiltsev et al] . Measured by hydrostatic level system.

SLAC tunnel drift studies

- **Goal:** to perform systematic studies of slow tunnel motion
- The linac alignment system working in the single Fresnel lens mode allowed submicron resolution
- First measurements of this kind were done in November 1995 by C.Adolphsen, G.Bowden and G.Mazaheri for a period of about 48hrs



Scheme of measurements

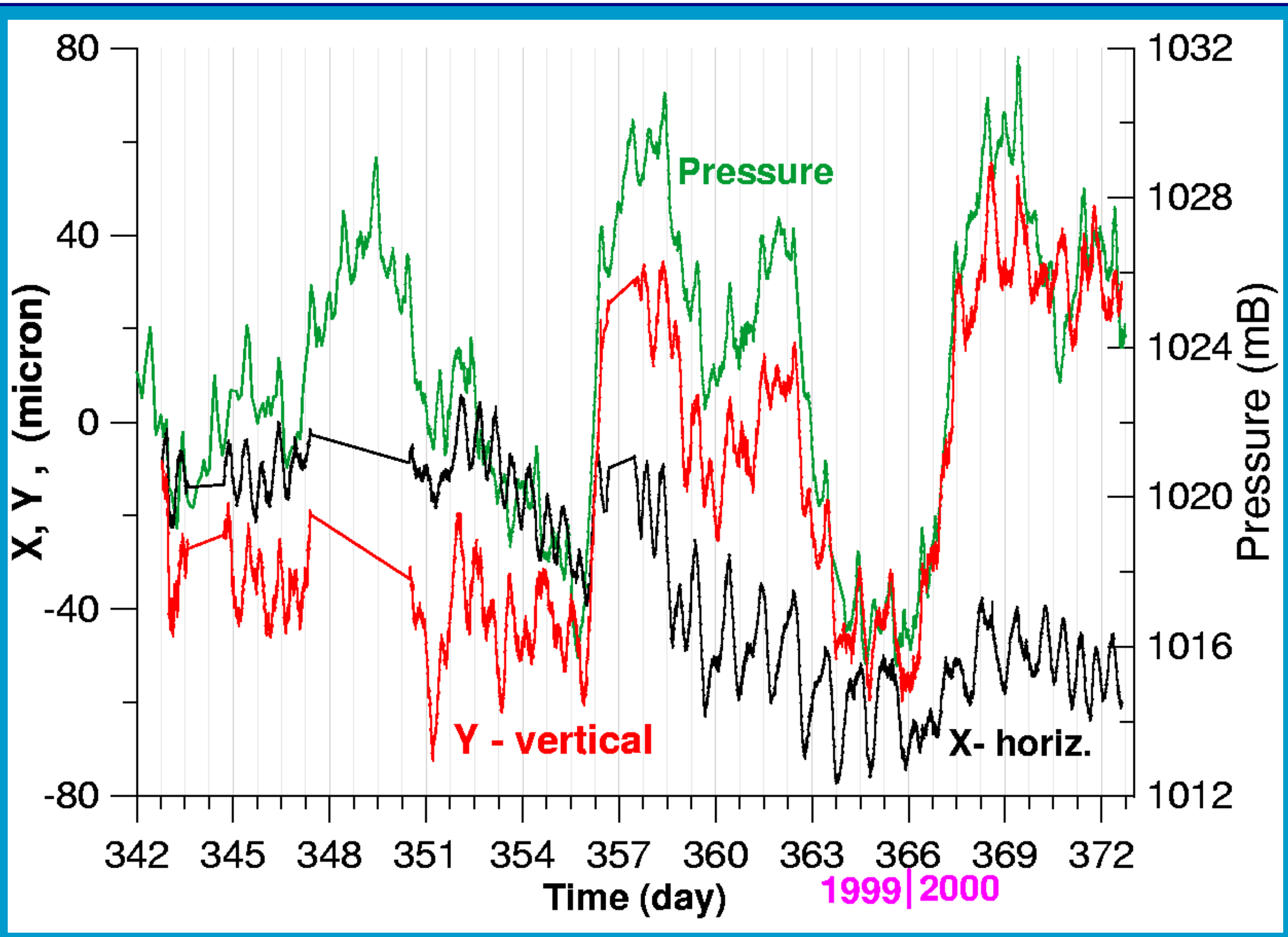
Signals from the quadrant photo detector were combined to determine X and Y relative motion of the tunnel center with respect to its ends.

Slow transverse relative drift of SLC tunnel

SLC tunnel deformation is correlated with atmospheric pressure

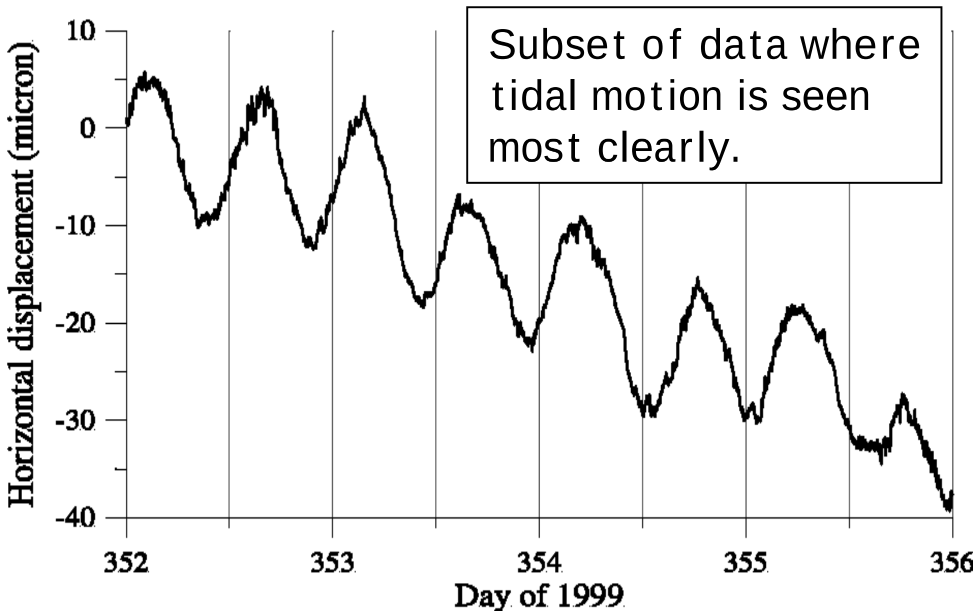
Reason:
landscape and ground property vary along the linac

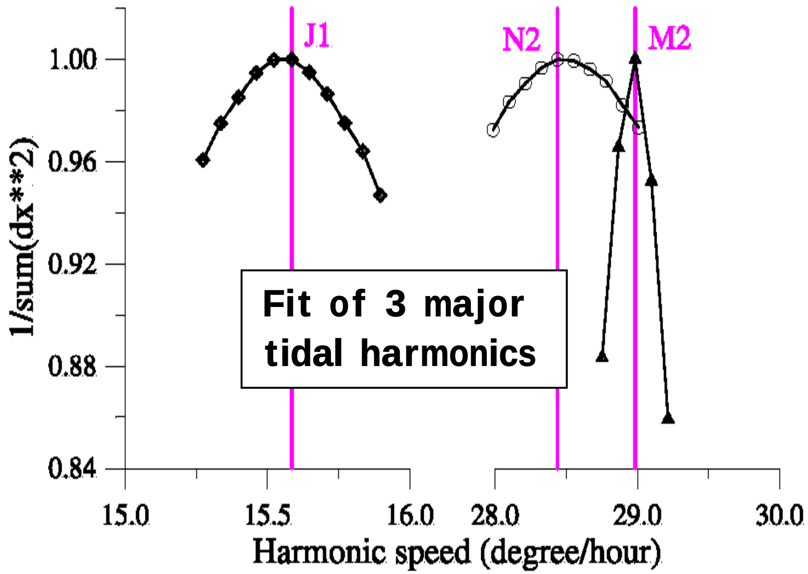
Motion shows diffusive or ATL character



Transverse displacement of the 3 km SLAC linac tunnel (center w. respect to ends) and atmospheric pressure.

Tidal motion of the SLAC linac tunnel





- **Observed tidal motion is ~100 times larger than expected.**

(N.B. the system is not sensitive to change of slope due to tides, but only to change of the curvature)

- **Higher amplitudes are caused by enhancement of tides due to ocean loading in vicinity (~500km) of the shoreline.**

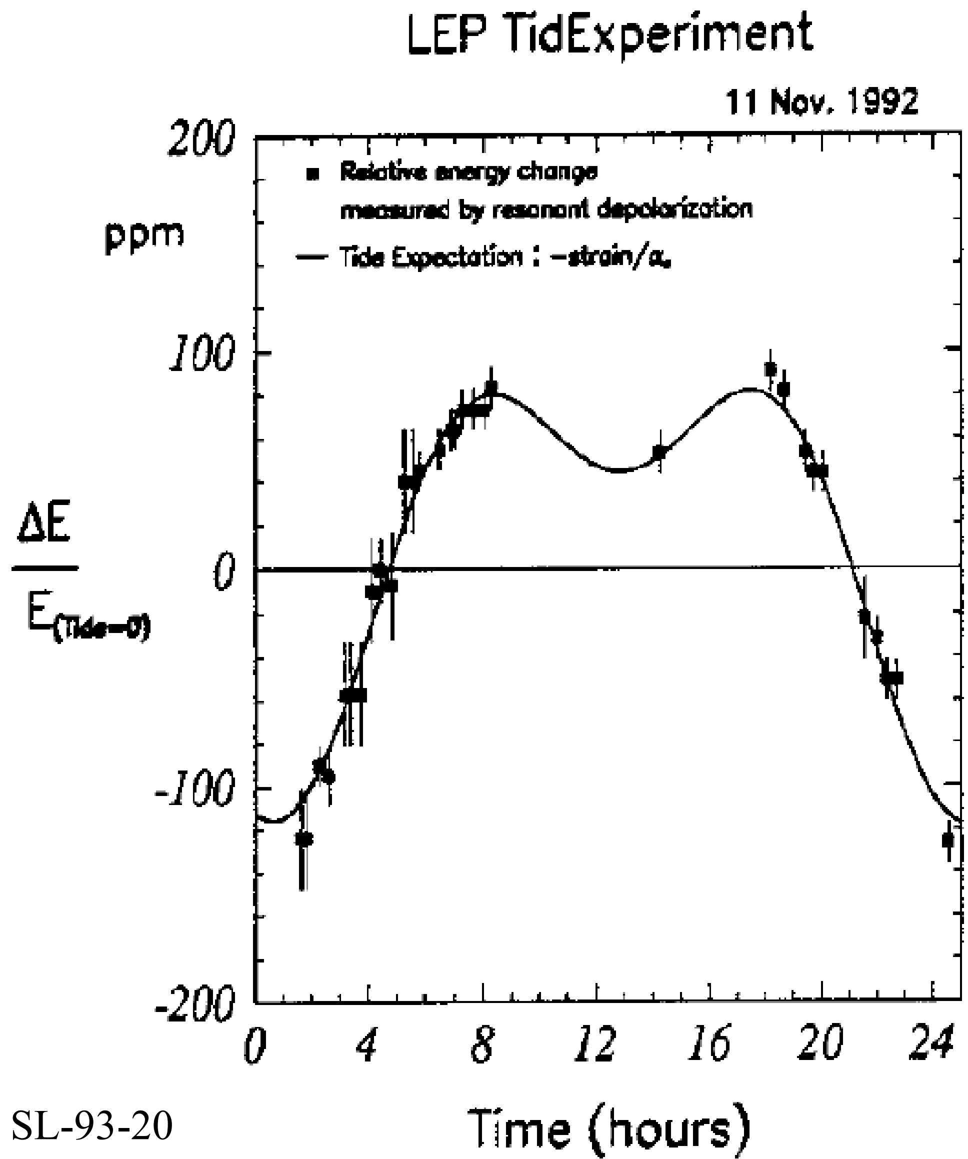
- **Tidal motion is slow, predictable, it has long wavelength and is not a serious problem for a collider.**

Tidal motion observed by LEP

- Change of LEP energy due to change of LEP circumference

- First order effect
- Surface move +-0.25m
- Radius change 4E-8

- Change of LEP circumference = 26.7km*4E-8 ~1mm



L.Arnaudon, et al. CERN SL-93-20

Slow transverse relative drift of SLC tunnel

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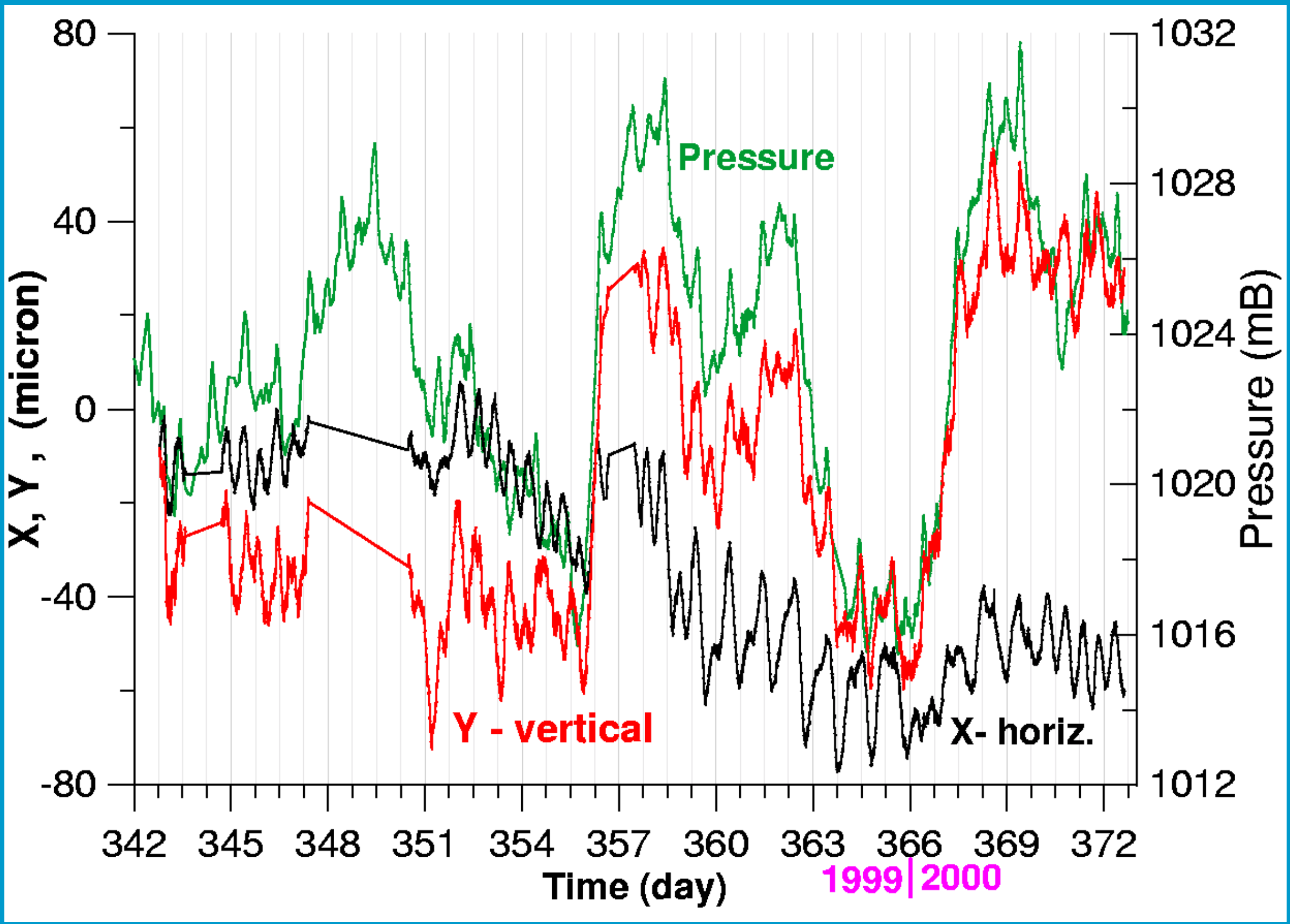
SLC tunnel deformation is correlated with atmospheric pressure

Reason:
landscape and ground property vary along the linac

Motion shows diffusive or ATL character



Transverse displacement of the 3 km SLAC linac tunnel (center w. respect to ends) and atmospheric pressure.

Influence of atmospheric pressure

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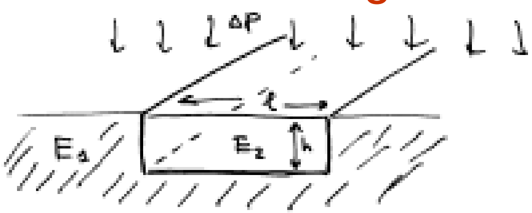
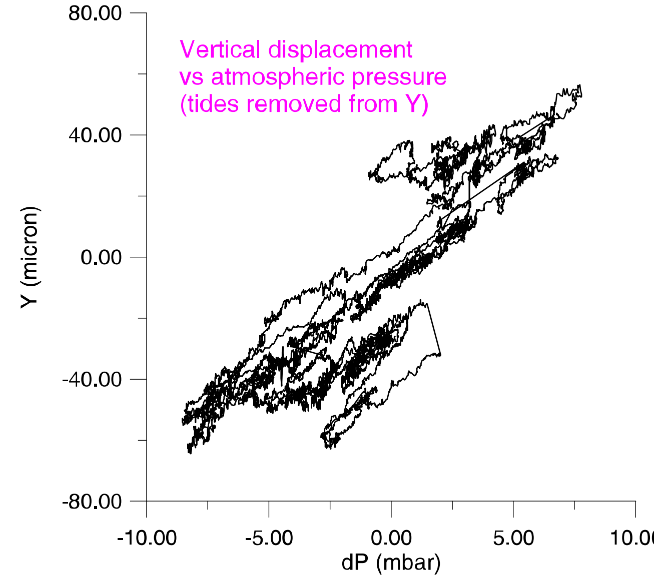
Very slow variation of external atmospheric pressure result in tunnel deformation.

Explanations: landscape and ground property variations along the linac:



$$\Delta h \approx \frac{\Delta P\, h}{E} \frac{\Delta E}{E}$$

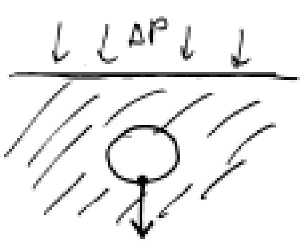


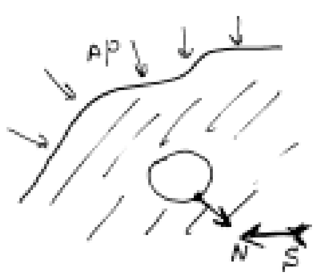
Observed Δh=50µm for ΔP=1000 Pa is consistent with these estimations if $\Delta E/E \sim 0.5$, $h \sim \lambda \sim 100$m, $\alpha \sim 0.5$ and $E \sim 10^9$ Pa.

Assumption $E \sim 10^9$ Pa is consistent with SLAC correlation measurements.

$$v \approx \sqrt{\frac{E}{2\rho(1+\nu)}}$$

Taking v=500m/s (at ~5Hz, I.e. $\lambda \sim 100$m) and $\rho = 2*10^3$ kg/m^3, we get E= 10^9 Pa





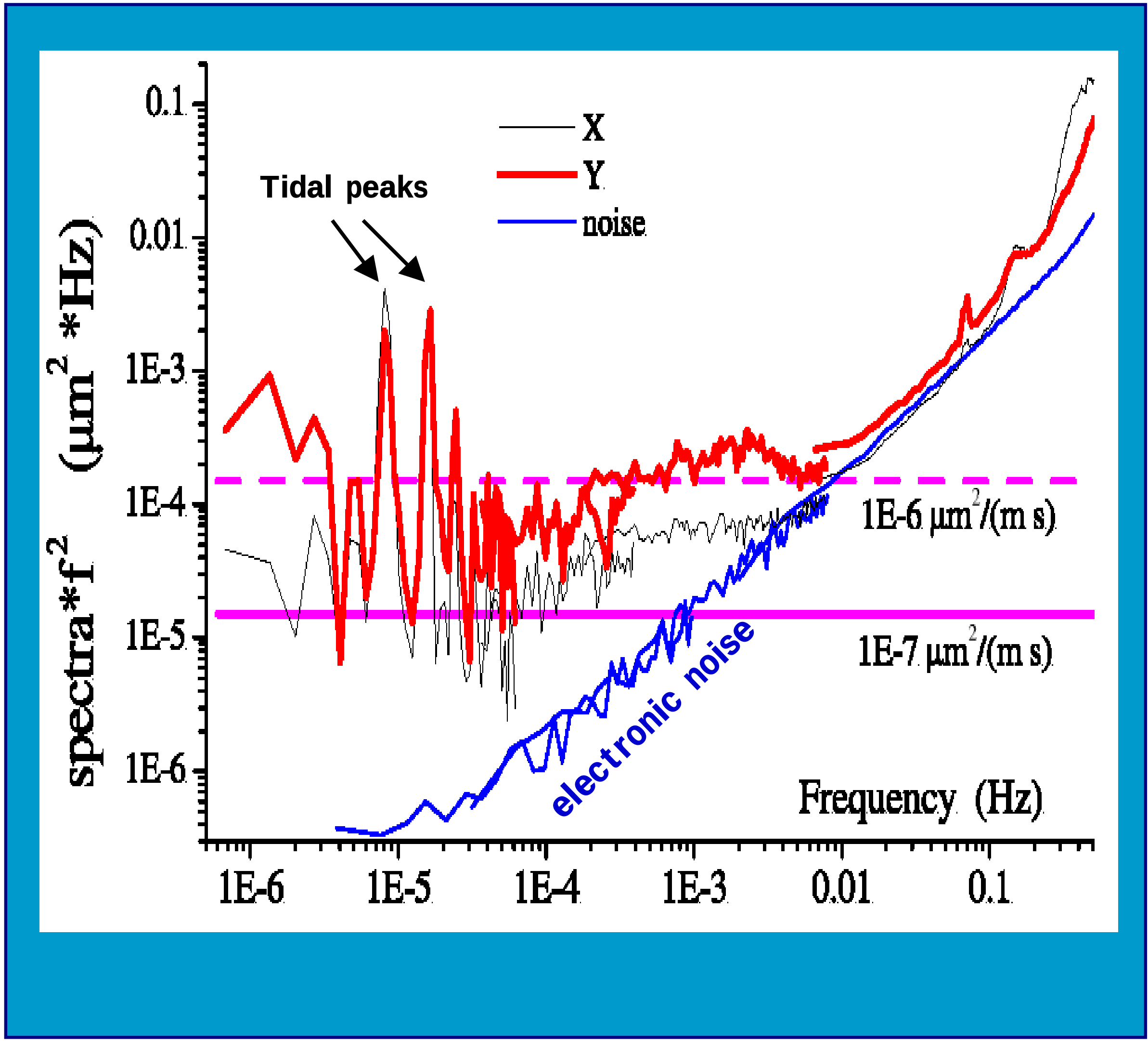
$$\Delta h \approx \frac{\Delta P}{E} \lambda \alpha$$

λ - length of landscape change,
α - variation of the normal angle to the surface

Tunnel motion. Diffusive in time

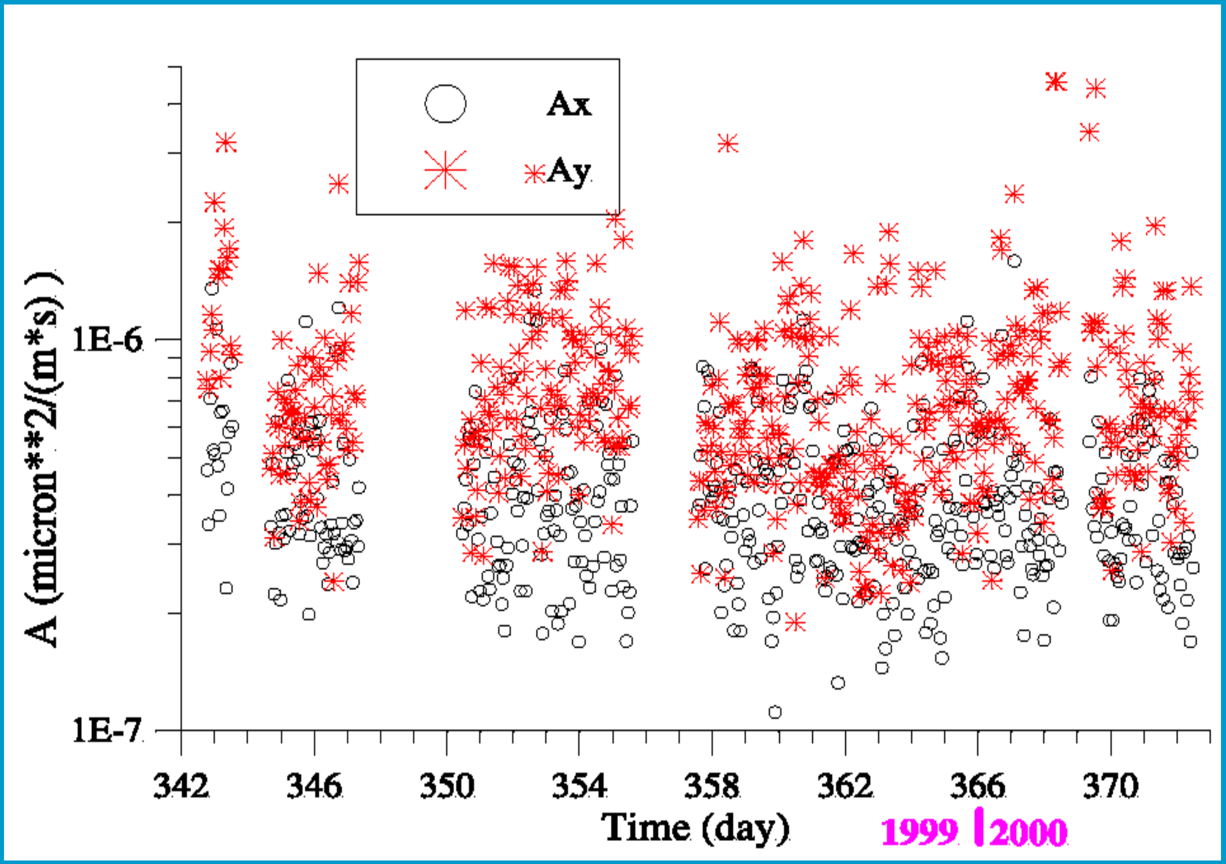
NLC

- **Spectra** of tunnel displacements behave as **$1/\omega^2$** in wide frequency range, as for the **ATL** law for which **$P(\omega,k)=A/(\omega^2\ k^2)$**



Electronic noise of the measuring system was evaluated with a light diode fixed directly to quadrant photo detector

Diffusive in time...



Parameter A found in 1999/2000 SLAC measurements.

- **fit of the spectra to ATL gives A~ 10^{-7} -- $2*10^{-6}$ $\mu m^2/m/s$**
- **"A" is higher for vertical plane.**
- **The value "A" varies in time. Why?**
- The "A" value is consistent with FFTB measurements with stretched wire over 30 m distance

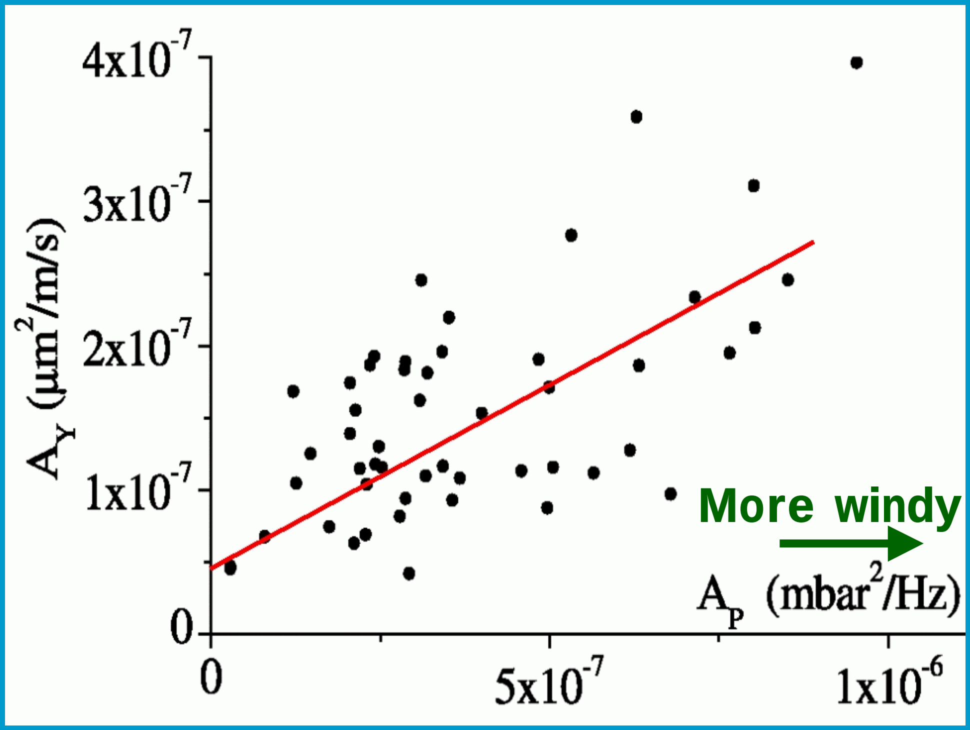
Atmosphere causes "A" of ATL to vary in shallow tunnel

NLC

- **Parameter A_D of ATL correlates** with amplitude of **atmospheric pressure variation**

- For **shallow tunnel** the **atmospheric contribution** to A_D **scales as $1/E^2$** (or as $1/v^4$, **v** – shear velocity) => need **strong ground !**

- For **deep tunnel** the **atmospheric contribution** to A_D **vanish**



"A" vs amplitude of atmospheric pressure spectrum A_p (which behaves as A_p/ω^2)

‘Slow’ Ground motion at NLC and TESLA

NLC

- **Diffusive or ATL motion:** $\Delta X^2 \sim A_D T L$ (minutes-month)
  (T – elapsed time, L – separation between two points)
- **TESLA : Low wakes -> smaller σ_E -> smaller $\Delta\varepsilon$ ($\sim \sigma^2_E$)**

Place	**A** $\mu m^2/(m \cdot s)$
HERA **R.Brinkmann,et al.**	$\sim 10^{-5}$
FNAL surface **V.Shiltsev,et al. TPAH111**	$(1\text{-}10)*10^{-6}$
SLAC*	$\sim 5*10^{-7}$
Aurora mine* **V.Shiltsev,et al. TPAH111**	$(2\text{-}20)*10^{-7}$
Sazare mine **S.Takeda,et al.**	$\sim 5*10^{-8}$

TESLA: Undisruptive realignment ~every month — OK for TESLA

NLC: Undisruptive realignment ~every 5hrs — OK for NLC

NLC: Undisruptive realignment ~every 2 days

*** Further measurements in Aurora mine, SLAC & FNAL are planned : TPAH116**

How to mitigate slow motion?

- Can we put more concrete into foundation and forget about slow motion? This is very unlikely:
  - we care about L~betatron λ~50m, => would need to make strength of foundation equivalent to ~50x50m^2 of soil
- Slow motion strongly depends on site and geology
  - Studies at KEK, SLAC, etc., helped to understand mechanisms and behavior of slow motion
- Careful selection of site (depth) – is a way to avoid the problem

'Slow' Diffusive Ground motion vs location

NLC

- **Diffusive or ATL motion:** $\Delta X^2 \sim A_D T L$ (minutes-month)
  (T – elapsed time, L – separation between two points)

Place	A $\mu m^2/(m{\cdot}s)$	method	~T,L	geology
HERA R.Brinkmann,et al.	$\sim 10^{-5}$	HERA beam	Hrs-month;30m	Glacial till
FNAL surface V.Shiltsev,et al.	$\sim (1\text{-}10)*10^{-6}$	double tube HLS	Min-days;10-100m	Glacial till; cut and cover
SLAC* R.Assmann,et al. A.Seryi, et al.	$\sim 5*10^{-7}$	stretched wire; laser alignment system	Min-hrs;30m Min-days;1500m	Sandstone; cut and cover
Aurora mine* V.Shiltsev,et al.	$(2\text{-}20)*10^{-7}$	double tube HLS	Min-month;10-100m	Dolomite; blasting
Esashi mine S.Takeda,et al.	$2*10^{-9}$	single tube HLS	Min-days;10-100m	Granite, TBM

*** Further measurements in Aurora mine, SLAC & FNAL are planned with better HLS system**

Diffusive Ground motion in Japan

[S.Takeda, KEK-99-135]

range ~10-100m, min-days

Place	**A** $\mu m^2/(m \cdot s)$	**geology**	**tunneling**
Tunnel of KEKB	$4*10^{-5}$	Sediment	
Kamaishi II-III	$1.4*10^{-7}$	granite	Slow blasting
Kamaishi I-II	$5.7*10^{-8}$	granite	Slow blasting
Sazare mine	$5*10^{-8}$	Green schist	
Esashi No.1	$5.7*10^{-9}$	granite	drilling
Esashi No.2	$2*10^{-9}$	granite	drilling

"Stability time" between beam-based realignments of a colliders ~1/A

Very slow (year-to-year) motion

- **Year-to-year** motion observed in tunnels seem to be **systematic** (~linear in time). SLAC, LEP, etc., as found by Rainer Pitthan
- Settlement (SLAC); underground water (LEP)
- Extrapolation of ATL parameter “A” from **year-to-year** measurements to **minute-hour** time scale is **invalid** and result in **overestimation of “A”.**

Systematic motion of SLAC linac shallow tunnel in 1966-1983

- **Year-to-year motion is dominated by systematic component**
- **Settlement**
- **Homogeneity of soil is important, but hard to achieve**

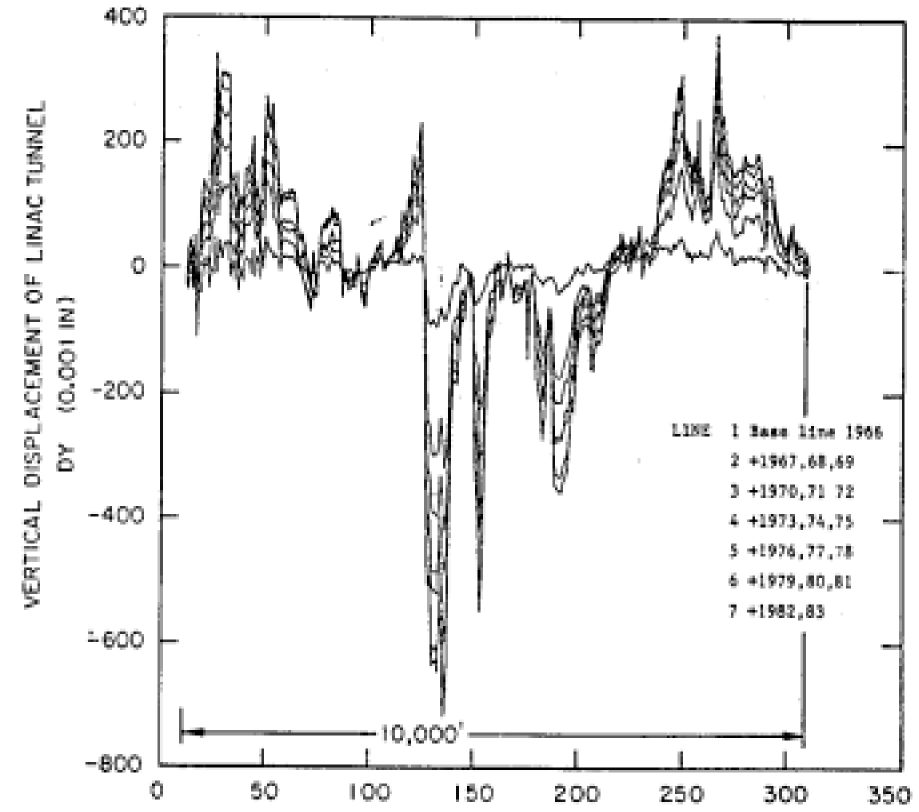
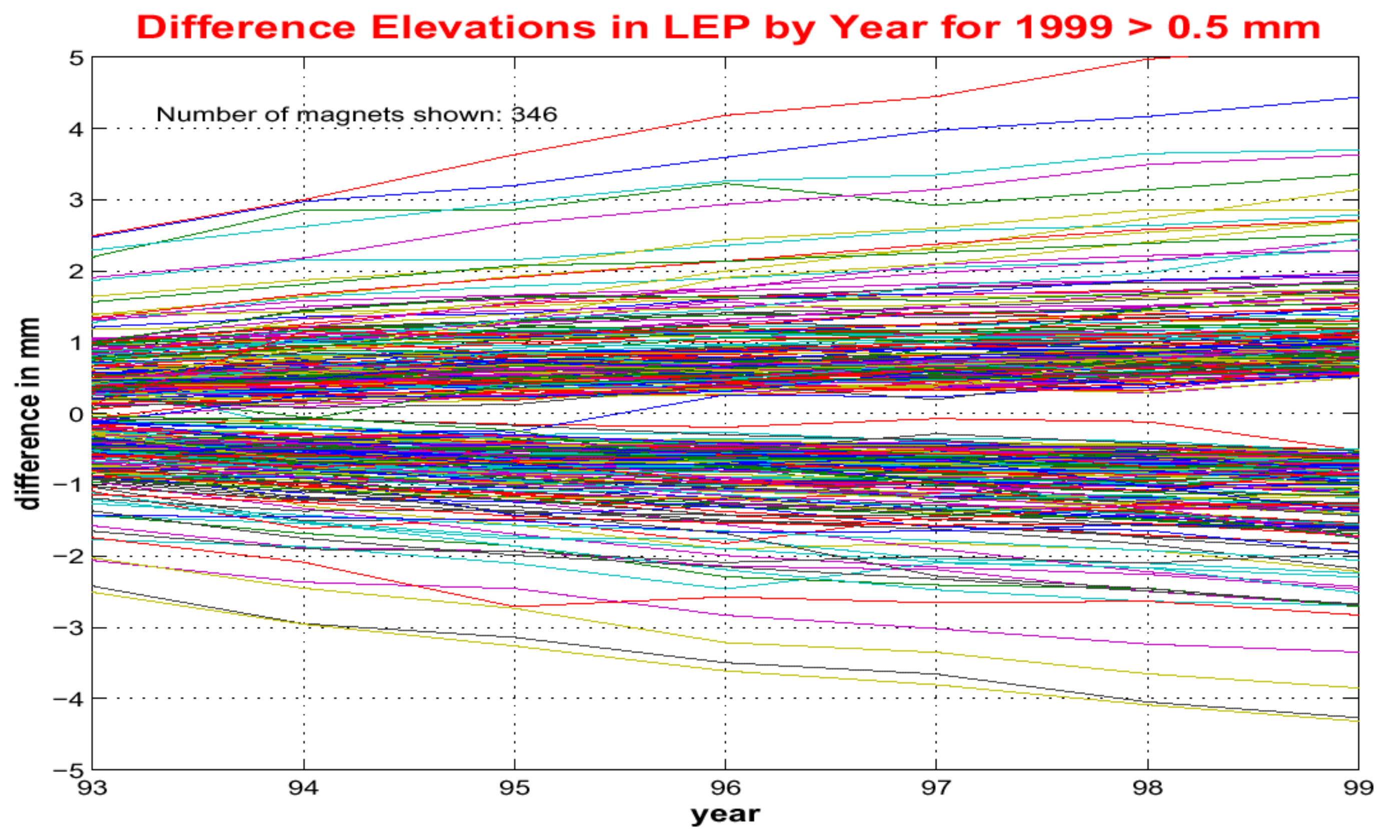


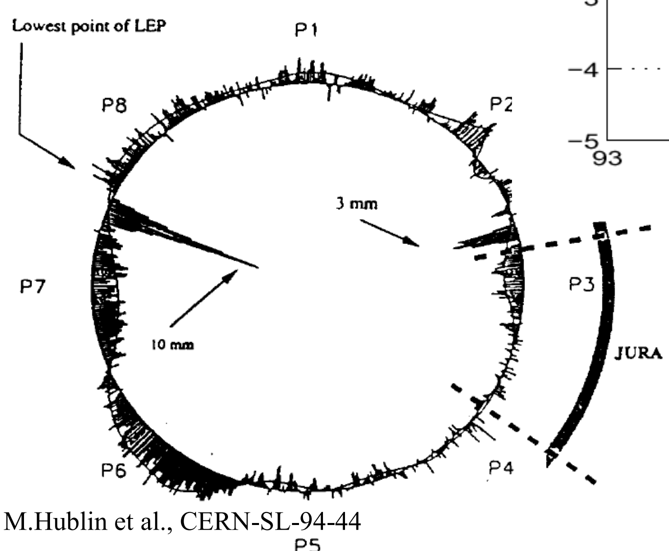
Figure 7: Displacement of the SLAC Linac Tunnel - Vertical.

Vertical displacement of SLAC linac for 17 years

[G.Fischer, M.Mayond 1988]

Example: Systematic motion at LEP
Difference of position of neighboring quads





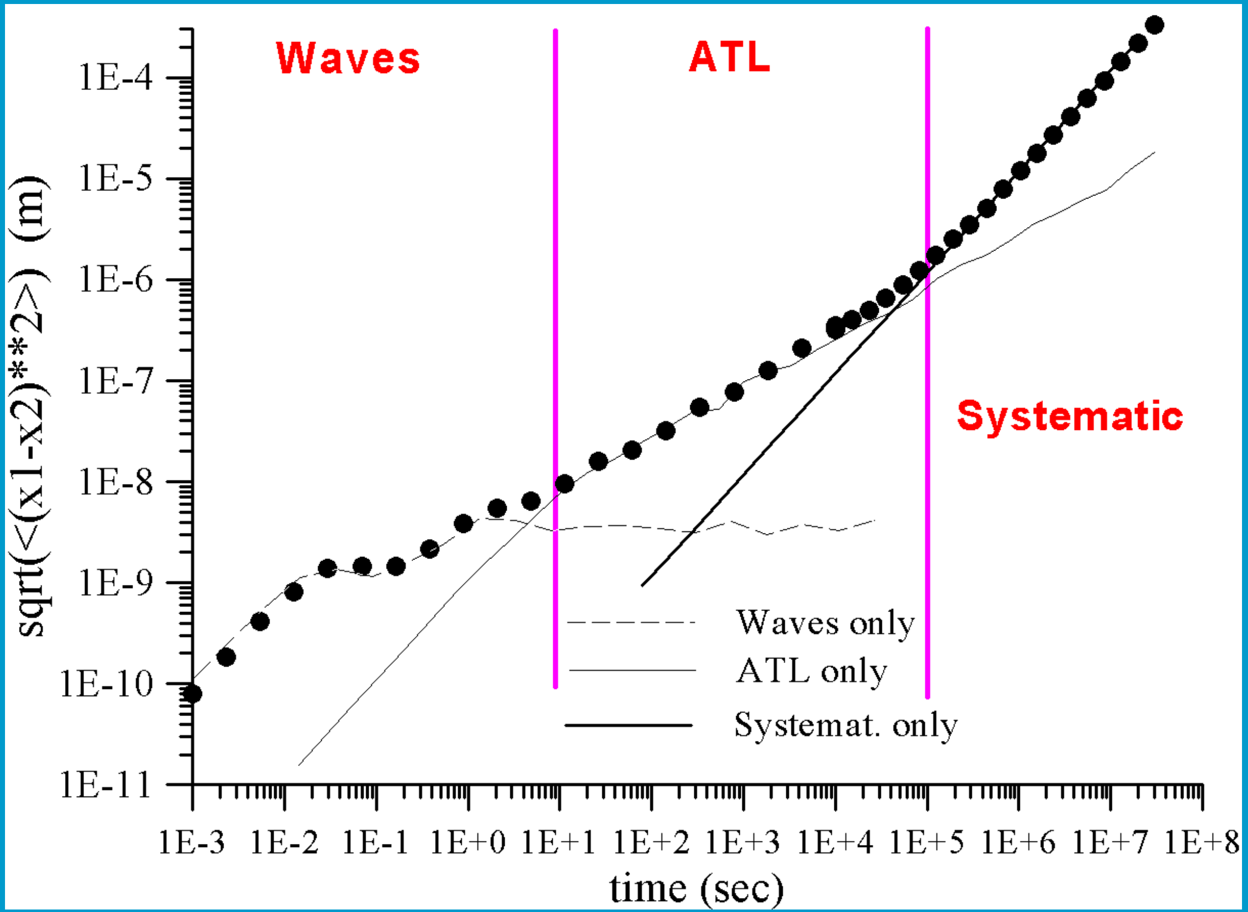
M.Hublin et al., CERN-SL-94-44

Rainer Pitthan, SLAC-PUB-8286, (1999)

Three types of motion in one model

- A ground motion model based on P(w,k) spectrum can be build to describe known properties of ground motion

- This model is included in several accel.phys. codes



<x^2> for SLAC site ground motion model

Slow motion questions and recommendations

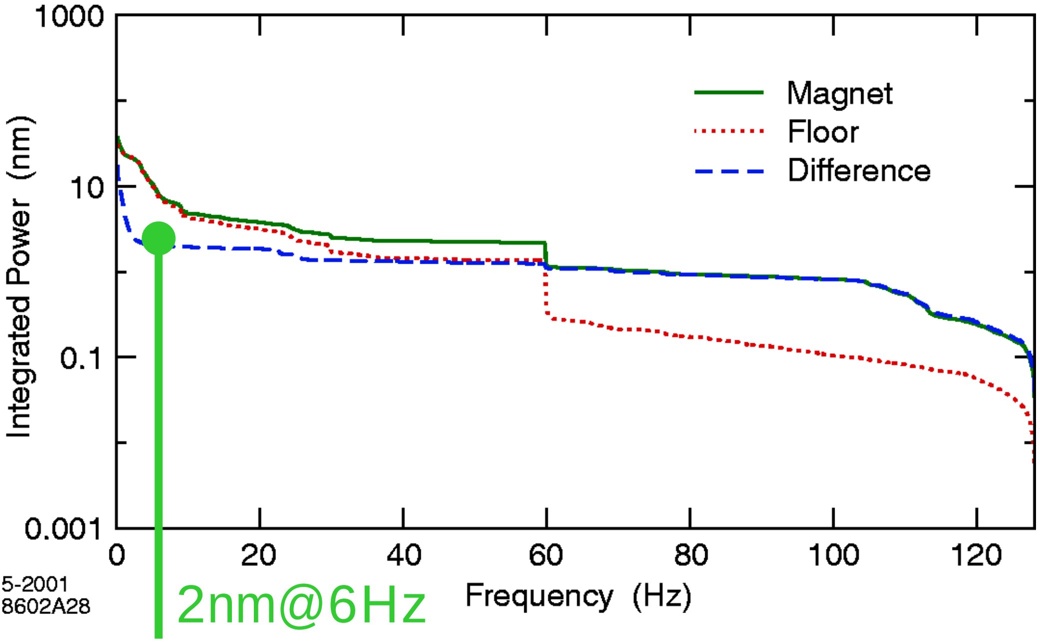
- **Reasons for slow motion**
  - Atmosphere, underground water, dissipation of high frequency motion. What else?

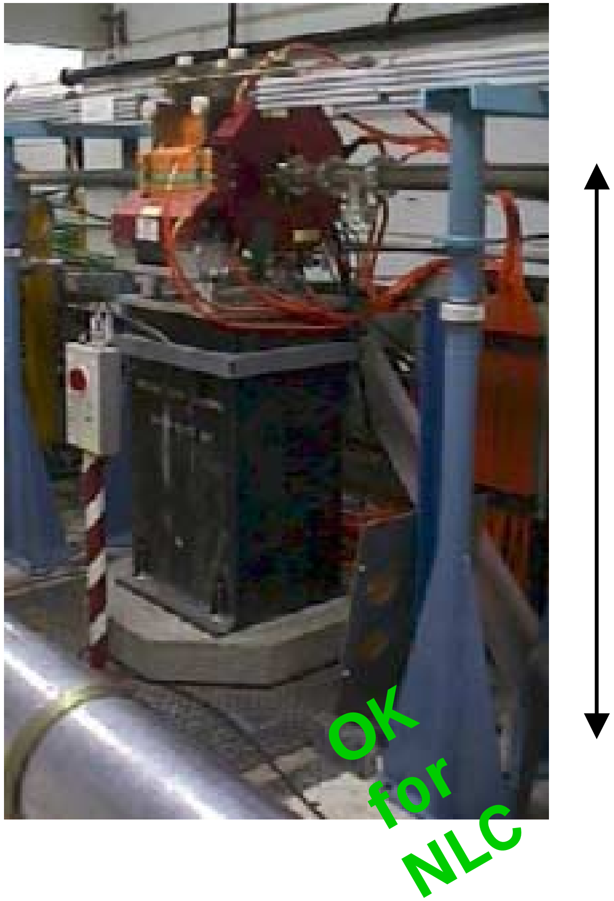
- **Dependence on geology, tunneling**
  - **Geology: good hard rock is preferable**
    => slow motion has lower amplitude
    => collider stability time is larger
  - **Tunneling**:
    => TBM preferable; avoid blasting

- **Dependence of slow motion on T, L, regions of validity of models need more investigations**
  - Further studies planned

One need to firmly connect to ground by good girders

- FFTB quad
  Only 2nm difference to ground
  (on movers, with water flow)





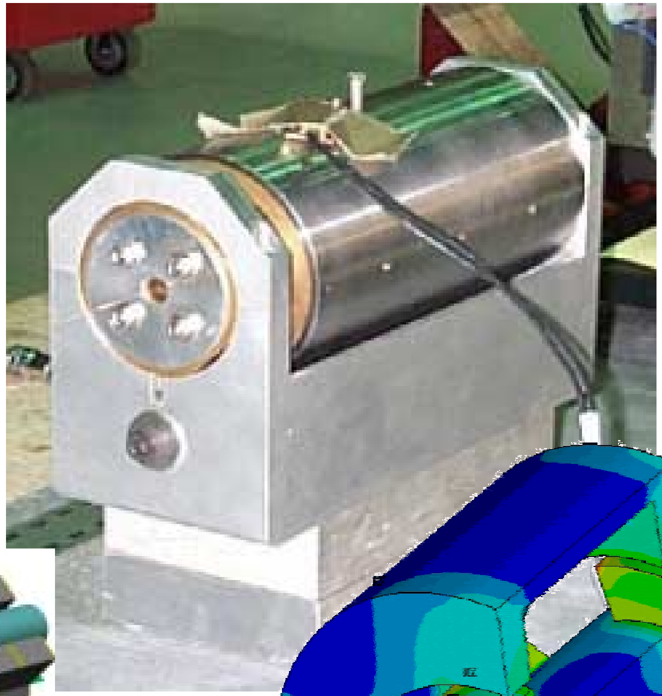
- **Further improvements:**
  - Lower girder; Lower water flow ; Smaller quad ; Perm.Magn. quad

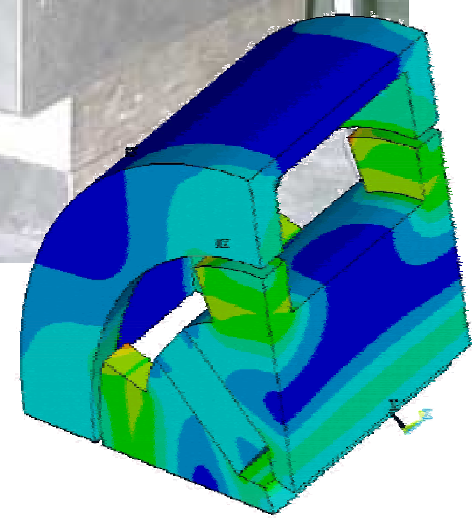
Linac quads need to be quiet & near vibration free

- Low water flow EM quads
- NLC **P**ermanent **M**agnet linac quad prototype

NLC PM sliding shunt quad

J.Volk et al., FNAL

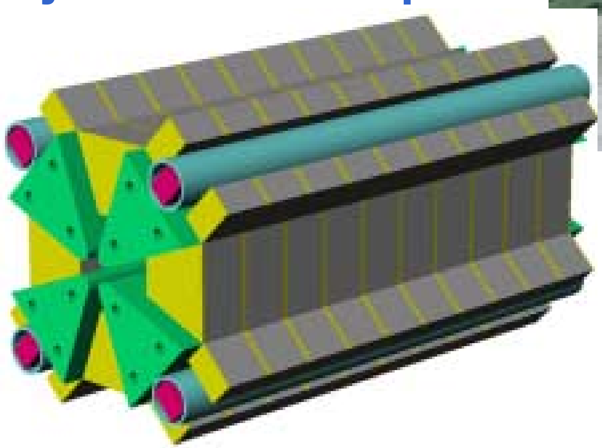




NLC linac EM quad

Ch.Spencer et al.

NLC linac corner adjustment PM quad



Conventional Facilities in&near tunnel noise need to be minimized

- Need to minimize CF noises
- Unusual practice for accelerators, but
- Inexpensive solutions exist
- Successfully used in LIGO
- Can be applied to NLC

Chiller equipment at the LIGO Hanford site

4Hz spring isolator

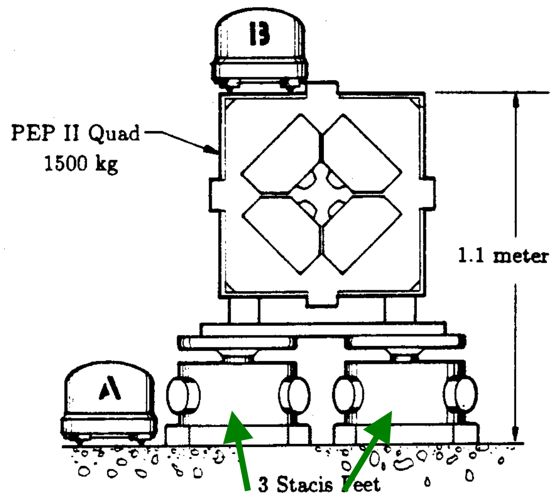
Courtesy: LIGO

LIGO = Laser Interferometer Gravitational-wave Observatory)

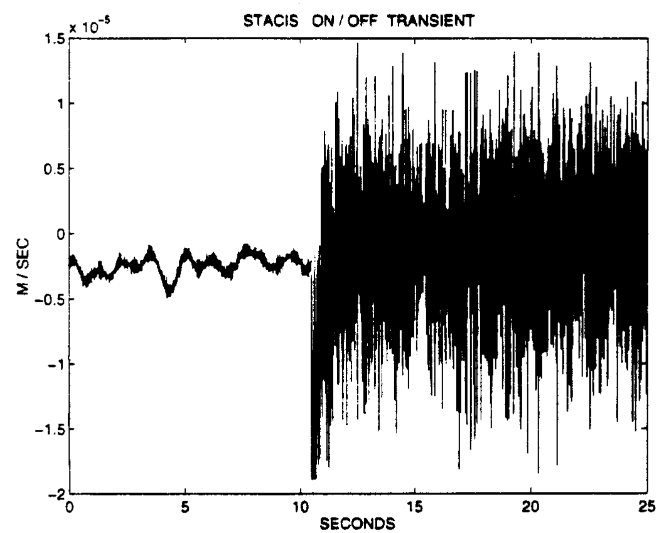
Stability of Final Doublet need to be provided by active methods

- FD feedback position stabilization and/or feedforward magnetic center correction

- 1996 – tests of STACIS
- Achieved:
  40nm -> 2nm for f>2Hz
  (in noisy room)



TMC STACIS
Active Piezoelectric
Vibration Control System



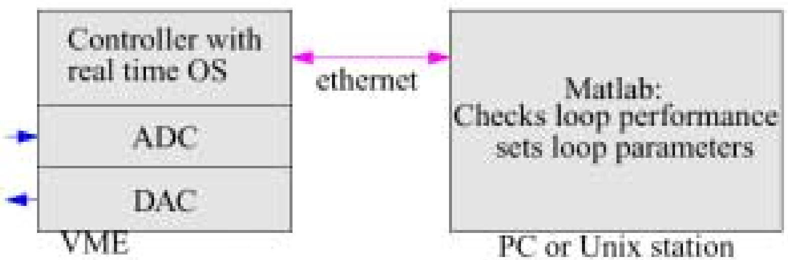
G.Bowden, et al. 96

- 2000-2001- develop digital feedback stabilization; compact; will optimize for 2 long FD; high magnetic field compatible

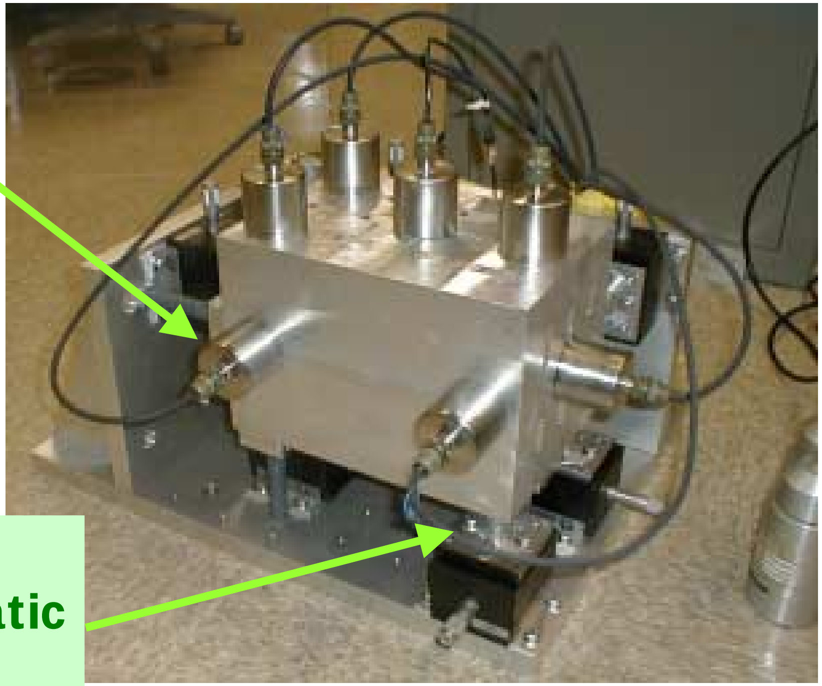
Inertial digital feedback is one of ways to keep Final Doublets steady

J.Frisch et al

- **Inertial stabilization in 6D at SLAC for NLC**



Digital feedback @ real time OS



Inertial sensors

Springs & electrostatic pushers

- **June 2001 – start of stabilization work**
- **Achieved ~10 times reduction, work to improve**
- **Next step: stabilize large realistic FD model**

IP collision stability

- TESLA needs fast IP feedback to provide collision stability
- Large bunch separation (300ns) simplifies its implementation

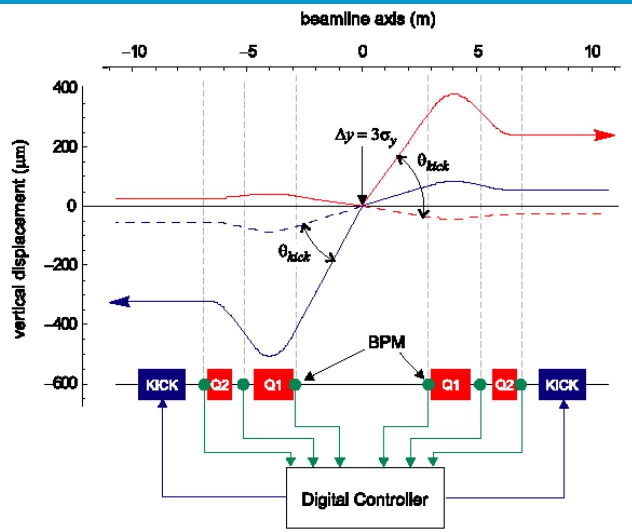


Figure 7.3.1: *The IP fast feedback system. The red and blue rays represent an example having a $3\sigma_y^*$ offset at the IP (corresponding approximately to a $10\sigma_{y'}^*$ kick). The dotted lines represent the trajectories with no beam-beam kick. Initial (example) IP angles are 1 and $2\sigma_{y'}^*$ for red and blue respectively.*

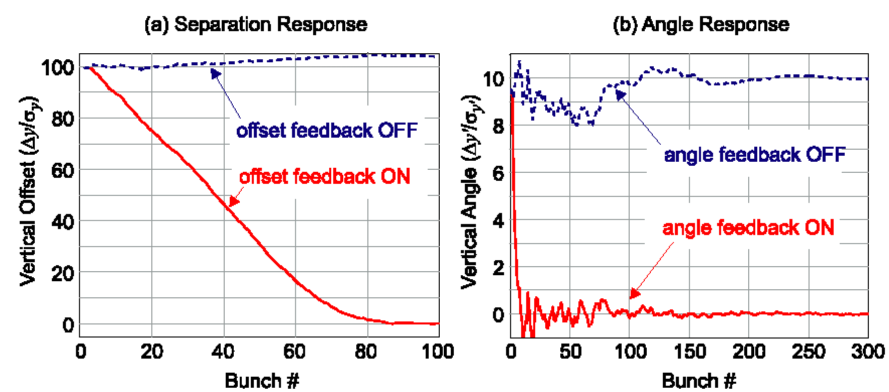


Figure 7.3.3: *Results of simulations of the IP fast feedback for (a) a $100\sigma_y$ offset step function and (b) a $10\sigma_{y'}$ angle step function. Included in the simulation are: residual effects of multi-bunch wakefields in the linac; signal BPM noise of 5 μm and 1 μm for the position and angle respectively; 0.1% kicker field imperfections; a 10% random variation in the beam-beam kick.*

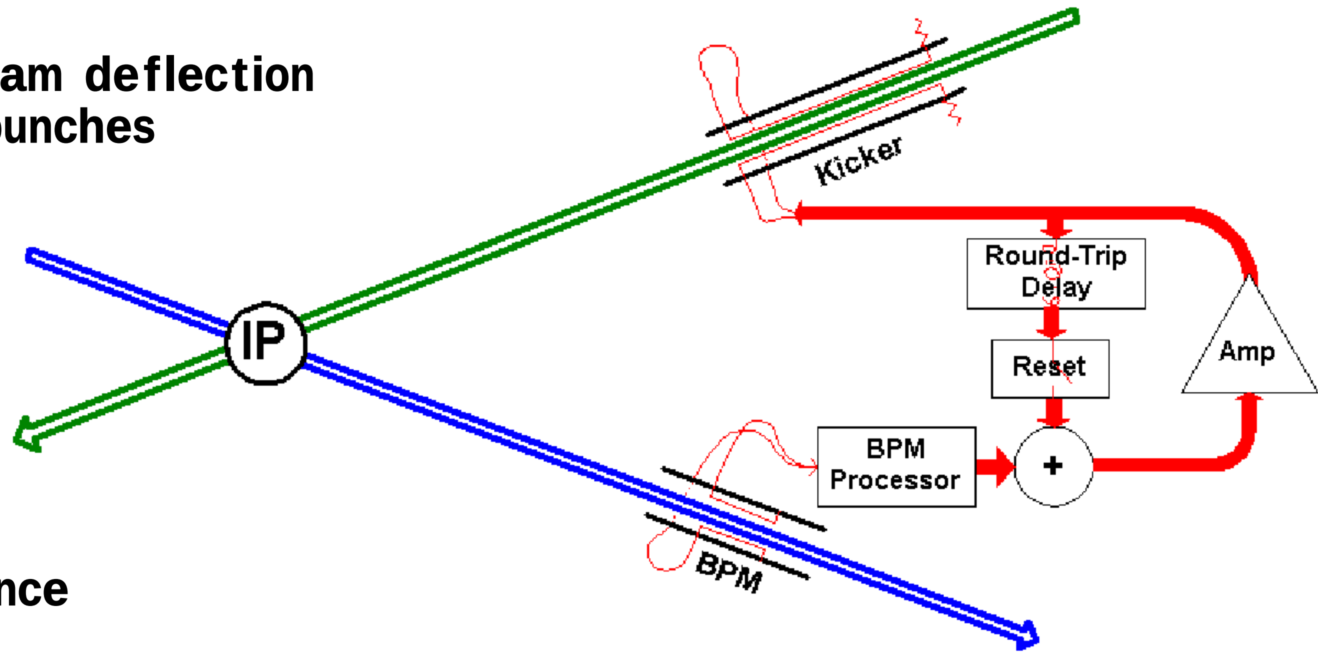
Pictures from TESLA TDR

Very Fast intratrain feedback for additional collision stability of NLC

- This is not a required, but additional NLC system
- It decreases sensitivity to beam jitter and ground motion

Oxford Univ., SLAC

- System concept:
  - Measure beam-beam deflection => correct next bunches
  - Stripline BPM and kicker
  - Feedback with round trip delay compensator for fast convergence
  - Off the shelf components



S.Smith, SLAC, LCC-0056, March 2001

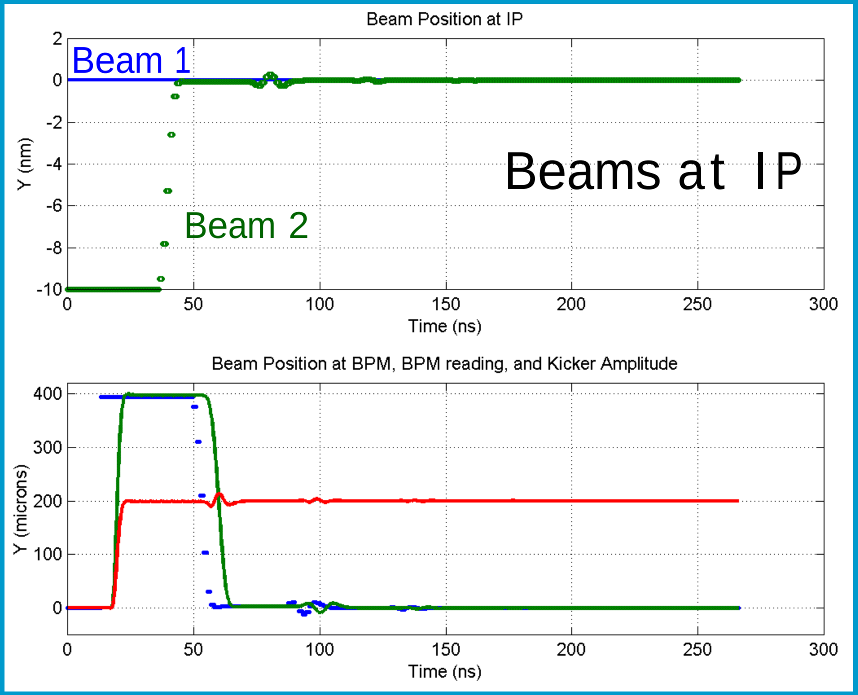
NLC Very Fast intratrain feedback

NLC

- Due to round trip delay compensator the convergence is very fast
- NLC stability will be provided by other systems, but
- Even if all other system fail, can recover almost full luminosity

  (80-50% for 5-50 σ beam jitter)
- Angle feedback is not yet included in considerations
- Now in lab, later beam tests

Capture transient for 10nm initial beam offset. Full NLC bunch train is shown



S.Smith, LCC-0056, March 2001

NLC

Summary

- Ground motion and vibration are important for any future collider
- Have measurements data from around the world; develop models of motion
- A lot of experience on beam-based feedbacks from SLC – basis for confidence
- Active suppression system being developed
- Learning from other fields (e.g. LIGO)
- It would require patience, but the problems appear solvable

NPSS Technology school, July 17, PM

Tuesday July 17, PM

Ground motion, Optimal Tunneling and Environmental Considerations for Future Colliders

Ground motion in future colliders Andrei Seryi (SLAC)

Optimal tunneling for future colliders Wilhelm Bialowons (DESY), Chris Laughton (Fermilab)

Conventional alignment - Now and in the future Catherine LeCocq (SLAC)

Beam based alignment - From an art to indispensable everyday tool Peter Tenenbaum (SLAC)